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# Effects of Ionizing Radiation on the Performance of Selected Tactical Combat Crews

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A general model is developed for characterizing the expected performance of four selected types of tactical army combat crews when the individual crewmembers function at degraded performance levels due to acute exposure to ionizing radiation. The model is also applicable to other situations that degrade individual crewmember performance. The results provide performance data for larger scale U.S. Army models that simulate battlefield conflicts where nuclear weapons might be employed. Performance-level data are generated as a function of dose and time after exposure for each crew type.

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# PREFACE

This report was prepared by Pacific-Sierra Research Corporation to describe the methodology for developing combat crew performance data based on a series of Intermediate Dose Program (IDP) studies sponsored by the Defense Nuclear Agency (DNA).

Work in this report, sponsored by DNA under contract DNA001-85-C-0352, utilizes the CREW-III model to determine the performance level of combat crew units taking the individual crewmember performance levels into consideration. Short duration tactical combat engagement scenarios are specified and performance levels are determined as a function of dose and time following ionizing radiation exposure.

The authors wish to express their appreciation for the assistance and cooperation of S. Levin; M. J. Moyer of Science Applications International Corporation, La Jolla, California; and for the direction and guidance of R. W. Young of DNA.

# CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

| MULTIPLY → TO GET | BY | TO GET ← DIVIDE |
|---|---|---|
| angstrom | 1.000 000 X E -10 | meters (m) |
| atmosphere (normal) | 1.013 25 X E +2 | kilo pascal (kPa) |
| bar | 1.000 000 X E +2 | kilo pascal (kPa) |
| barn | 1.000 000 X E -28 | meter$^2$ ($m^2$) |
| British thermal unit (thermochemical) | 1.054 350 X E +3 | joule (J) |
| calorie (thermochemical) | 4.184 000 | joule (J) |
| cal (thermochemical)/cm$^2$ | 4.184 000 X E -2 | mega joule/m$^2$ ($MJ/m^2$) |
| curie | 3.700 000 X E +1 * | giga becquerel (GBq) |
| degree (angle) | 1.745 329 X E -2 | radian (rad) |
| degree Fahrenheit | $t_k$ = (t°f + 459.67)/1.8 | degree kelvin (K) |
| electron volt | 1.602 19 X E -19 | joule (J) |
| erg | 1.000 000 X E -7 | joule (J) |
| erg/second | 1.000 000 X E -7 | watt (W) |
| foot | 3.048 000 X E -1 | meter (m) |
| foot-pound-force | 1.355 818 | joule (J) |
| gallon (U.S. liquid) | 3.785 412 X E -3 | meter$^3$ ($m^3$) |
| inch | 2.540 000 X E -2 | meter (m) |
| jerk | 1.000 000 X E +9 | joule (J) |
| joule/kilogram (J/kg) (radiation dose absorbed) | 1.000 000 | Gray (Gy) |
| kilotons | 4.183 | terajoules |
| kip (1000 lbf) | 4.448 222 X E +3 | newton (N) |
| kip/inch$^2$ (ksi) | 6.894 757 X E +3 | kilo pascal (kPa) |
| ktap | 1.000 000 X E +2 | newton-second/m$^2$ ($N-s/m^2$) |
| micron | 1.000 000 X E -6 | meter (m) |
| mil | 2.540 000 X E -5 | meter (m) |
| mile (international) | 1.609 344 X E +3 | meter (m) |
| ounce | 2.834 952 X E -2 | kilogram (kg) |
| pound-force (lbs avoirdupois) | 4.448 222 | newton (N) |
| pound-force inch | 1.129 848 X E -1 | newton-meter (N-m) |
| pound-force/inch | 1.751 268 X E +2 | newton/meter (N/m) |
| pound-force/foot$^2$ | 4.788 026 X E -2 | kilo pascal (kPa) |
| pound-force/inch$^2$ (psi) | 6.894 757 | kilo pascal (kPa) |
| pound-mass (lbm avoirdupois) | 4.535 924 X E -1 | kilogram (kg) |
| pound-mass-foot$^2$ (moment of inertia) | 4.214 011 X E -2 | kilogram-meter$^2$ ($kg-m^2$) |
| pound-mass/foot$^3$ | 1.601 846 X E +1 | kilogram/meter$^3$ ($kg/m^3$) |
| rad (radiation dose absorbed) | 1.000 000 X E -2 ** | Gray (Gy) |
| roentgen | 2.579 760 X E -4 | coulomb/kilogram (C/kg) |
| shake | 1.000 000 X E -8 | second (s) |
| slug | 1.459 390 X E +1 | kilogram (kg) |
| torr (mm Hg, 0° C) | 1.333 22 X E -1 | kilo pascal (kPa) |

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

# SECTION 1
# INTRODUCTION

This report is one of a series which provides the documentary basis of study efforts to quantify the effects of intermediate level gamma and neutron doses on the combat effectiveness of tactical combat forces. The effort herein builds on the work of the Intermediate Dose Program (IDP), where models were developed to determine the expected performance level of individual soldiers as a function of dose and time after exposure [Anno, Wilson, and Dore, 1983]. While prior IDP work characterized the expected performance of individual soldiers, here that work is extended to small army combat crew units. Four types of crews selected for this study are shown in Table 1, along with a brief description of the specific combat engagement action of each. These crews are all associated with vehicular equipment and represent a significant portion of the tactical force structure.

The methodology followed in developing combat crew performance levels is outlined in Fig. 1. There were two specific objectives of this study. The first was to determine a relationship for the collective performance of a crew as a function of the performance levels of each of the crewmembers. For a typical crew with four crewmembers, the resulting model, as indicated in Fig. 1 under "Four-dimensional functional fits," required eight parameters, two each for the four independent variables (crewmember performances). This relationship can be used in simulation codes such as Ballistic Research Laboratory's (BRL) AURA [Klopcic and Roach, 1984] to predict battlefield performance of a crew for an arbitrary mix of degraded crewmembers. It applies regardless of the underlying cause of the degraded performances, whether due to radiation sickness or some other physical or psychological trauma.

Given the above crew performance algorithm, the second objective was to develop a formalism for determining crew performance as a function of acute dose external to the crew vehicle and time after exposure. This formalism, as depicted in the lower portion of Fig. 1,

Table 1. Selected Army combat crews.

| Crew Type | No. of Tasks | Crewmembers | No. of Tasks | Brief Description of Engagement Actions | Normal Time (s) |
|---|---|---|---|---|---|
| M109 howitzer Gun crew | 11[a] | 1 Chief of section | 6 | Set up, aim, load, | 103.2 |
| | | 2 Gunner | 3 | and fire 2 rounds | |
| | | 3 Assistant gunner | 2 | | |
| | | 4 No. 1 cannoneer | 13 | | |
| Fire direction center (FDC) | 26 | 1 Fire direction officer | | Acquire, calculate, | 33.6 |
| | | 2 Computer | 4 | and transmit target | |
| | | 3 Radio telephone operator observer to battery)[b] | [c] | firing data to battery | |
| M60A3 tank crew | [c] | 1 Tank commander | 19 | Acquire target, emerge | 28.1 |
| | | 2 Gunner | 1 | from cover, fire, | |
| | | 3 Loader | [c] | reload 2 rounds | |
| | | 4 Driver | 4 | and resume cover | |
| M901 ITV TOW crew | 24 | 1 Squad leader | 7 | Move to site | 197.8 |
| | | 2 Gunner | 5 | sequentially fire | |
| | | 3 Driver | 2 | and guide both | |
| | | 4 Loader | 3 | missiles and reload | |

[a] Includes 2 recoils
[b] Fixed times
[c] Inferred, no data

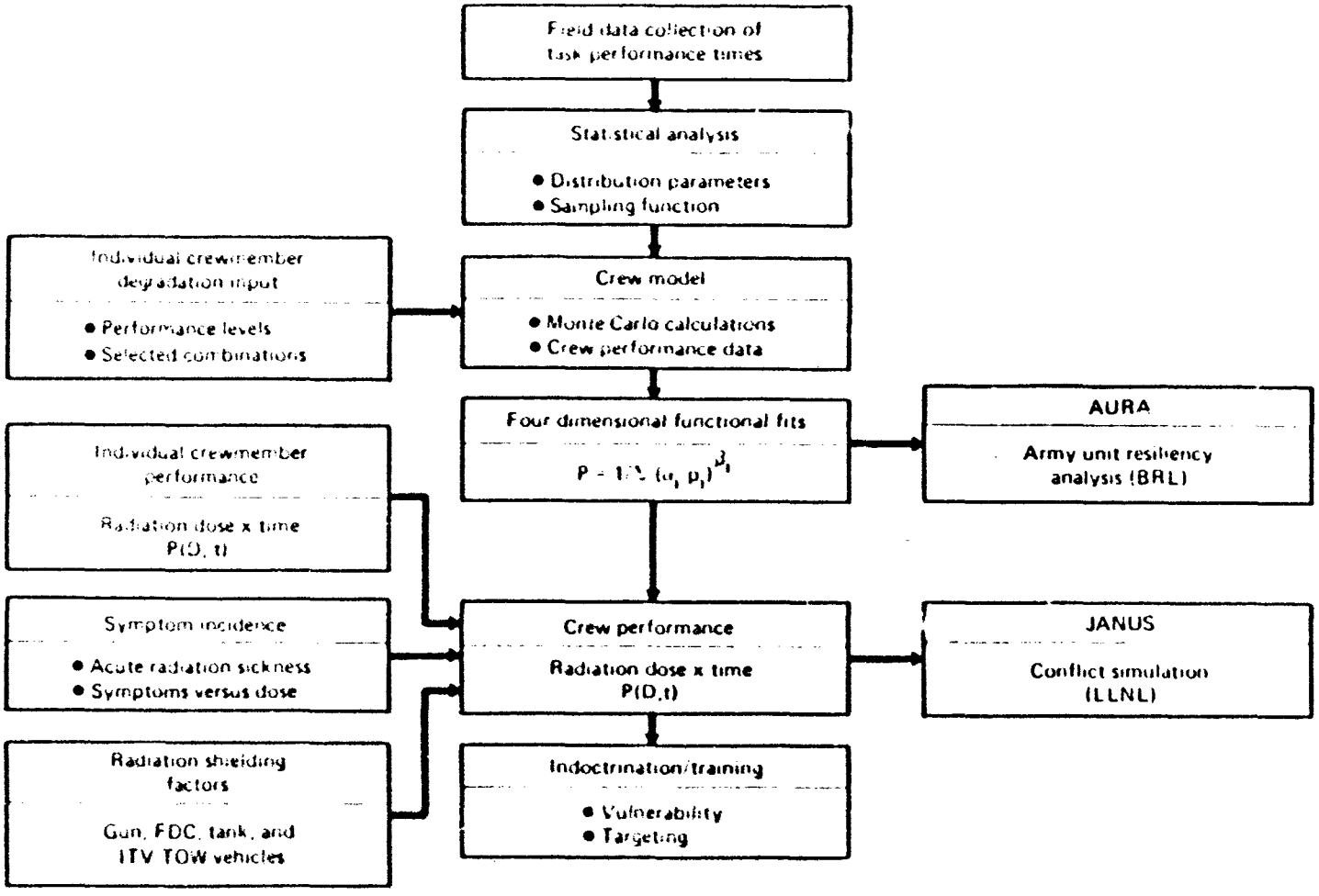



Figure 1. Combat crew performance--methodology.

combines a number of factors to yield the desired crew unit performance. Among these factors are: radiation shielding by the vehicle, the variability among individuals in expressing symptoms of radiation sickness, the crew performance algorithm, and results from the IDP studies of dose and time-dependent individual crewmember performance. A complete dose and time-dependent performance surface was then prepared for each crew type by assuming typical vehicle shielding factors and averaging over the distribution of symptom incidence. This set of surfaces is suitable for implementation on higher level combat simulation codes, such as the JANUS code at Lawrence Livermore National Laboratory (LLNL) [Blumenthal et al., 1984].

In this study, performance is expressed as the ratio of the time normally required to complete the specified combat engagement with crewmembers unaffected by radiation (the normal mission time) to the time required when the performance level of one or more crewmembers is degraded (slower) from the effects of radiation. This definition was adopted [Anno, Wilson, and Dore, 1983] in the earlier IDP study of individual crewmembers and has the desirable properties of always yielding a value between zero and one as well as being amenable to empirical field measurements.

A combat engagement consists of a number of tasks shared among the individual crewmembers that must be completed according to a predetermined sequence. The performance of each crewmember is expressed quantitatively in terms of the time taken to complete his assigned tasks. The combat engagements are all very brief, ranging from about 30 s to 1.5 min, and represent critical durations of combat where crewmembers are required to flawlessly execute a large number of often split-second tasks in a coordinated team effort. Accordingly, such intense combat engagements represent critical elements affecting the outcome of tactical battlefield encounters.

In the sections that follow, we discuss the methodology (summarized in Fig. 1) developed for determining degraded performance levels for each of the four combat crew units. The appendices contain numerous tables and diagrams referred to in the discussion that provide detailed backup information and data.

## SECTION 2
## ANALYSIS OF EMPIRICAL DATA

Studies have assembled a large number of field measurements of the time required by trained military personnel to perform the tasks comprising the engagements described in Table 1. The M60A3 tank data [Moyer and Lam, 1987] were combined with data for three other crew types: the M109 howitzer, fire direction center (FDC), and M901 Improved TOW (tube-launched, optically tracked, wire-guided) Vehicle (ITV-TOW) crews [Moyer, O'Donoghue, and Feinberg, 1984]. These data were taken from multiple repetitions of standard operational engagements by trained soldiers. A brief description of each engagement is included in Table 1, and more detailed descriptions of the specific tasks are tabulated in Appendix A.

The goal was to generate an accurate, dynamic model for each crew type. The empirical data gathered were suitable for statistical evaluation to provide the following critical inputs to such a model:

1. Representative mean times for each task
2. Variances about the mean times for crewmembers
3. Detailed chronological sequence and hierarchy of task executions to allow construction of task interaction diagrams

The scope and extent of the measurements for all four crew types is summarized in Table 2. Most tasks for most crew types were performed five or more times by several different crews comprised of different individuals. However, because only a limited number of qualified personnel were available for certain positions, they were required to occupy those positions for all of the trials. For example, for the gun crew a single individual (chief of section) participated in each of the 11 separate crew units. This crewmember performed two of the same tasks five times each for a total of 55 trials. Also, because certain tasks involved the actual firing of

Table 2. Structure of empirical-task time measurements.

| Crew Type | No. of Tasks | No. of Separate Crew Units | No. of Separate Individuals | No. of Trials Each |
|---|---|---|---|---|
| Gun crew | 2 | -- | 1 | 55[a] |
| | 25 | 11 | 33 | 5 |
| FDC | 23 | 10 | 30 | 5 |
| Tank crew: COFT | 18 | 15 | 30 | 7 to 12 |
| Tank crew: Live | 4 | 10 | 10 | 1 |
| | 2 | 4 | 4 | 10 |
| ITV-TOW crew | 7 | -- | 2 | 20[a] & 30[a] |
| | 12 | 5 | 10 | 10[a] |

[a]Only the last 5 trials were used.

expensive, live ordinance, those tasks were not repeated as often. In Table 2, two rows of numbers are used for all crew types but the FDC. The upper numbers represent situations in which the number of qualified personnel was limited.

The entry in Table 2 for the M60A3 tank crew is divided in two because task time measurements of the tank crewmembers were made in two separate environments. The many rapidly occurring tasks for the tank commanders and gunners required that timings be taken in a standard tank simulator, the "conduct of fire trainer" (COFT). This simulator is stationary and does not fire; therefore, the loader and driver tasks were possibly not realistic representations of an actual tank environment in some respects. However, a limited number of loader and driver task timings were taken in real tanks participating in exercise maneuvers. These exercises included live firing of the gun. The two subdivisions given for the tank crews in Table 2

delineate the tasks and number of trials applicable to each set of measurements.

The final mean times and variances for these empirical data are tabulated in Appendix A. Except for the tank crew, these result from five independent trials by each individual. Where more trials were available, only the last five were used. Occasionally, an individual would have only four valid trials; in these cases, the standard statistical practice was employed of introducing an artificial fifth trial equal to the mean of the four valid trials. For the tank crews, however, all available data were used.

Of concern was the possibility of a "learning curve" effect in which a trend towards shorter times would develop with successive trials by an individual. Correlation tests were performed to determine if any systematic trend could be found in going from the first to the fifth trial. Neither a trend toward longer times (due to boredom with repetitions of the same exercise) nor toward shorter times (learning curve) was discernible.

The complete lack of any appropriate data on crewmembers in degraded states was one of the major concerns of this study. In particular, a method was needed for estimating the variance about the mean task times for degraded crewmembers. The solution was to model the variance as a function of the mean, assuming the same functional form to hold for both the degraded and undegraded situations.

Let $T_i$ be the normal (undegraded) mean time for completing task i. Then the performance of a crewmember is defined as $p = T_i/t_i$, where $t_i$ is the longer time required to accomplish the same task when the crewmember is in a degraded state. So for a given performance level p, the mean time for a degraded crewmember to perform task i is just $\mu_i = T_i/p$. A model for the variance about $\mu_i$ is desired. If, for healthy crewmembers, a functional relationship of the form $\sigma^2 = f(\mu)$ were found, then we could approximate the degraded variance by assuming:

$$\frac{\sigma^2_{deg}}{\sigma^2_{norm}} = \frac{f(\mu/p)}{f(\mu)} \quad . \qquad (1)$$

A scatter plot of $\sigma_i$ versus $\mu_i$ was made for each crew type, and a combined plot for all four crew types is shown in Fig. 2. It is immediately obvious that the upward, linear trend is very nebulous.

Grouping tasks according to the type of activity was then considered. The types chosen were:

1. cognitive,
2. physically demanding,
3. normal.

This partitioning of tasks was suggested by the previous IDP study, where trends were observed indicating that certain physically demanding tasks deviated substantially from the norm. A physically demanding task is one that would more effectively fatigue a crewmember compared to other tasks and thus lengthen task performance time. Similar deviations were also observed for certain FDC tasks which require intense mental concentration. These "cognitive" tasks are indicated by a "C" in the column titled "Task Type" in Appendix B. The physically demanding tasks are similarly marked with a "P." The remainder of the tasks are normal and are unmarked.

Examples of scatter plots of $\sigma_i$ versus $\mu_i$ for these activity groupings are shown in Fig. 3. Again, only a very diffuse trend is evident. To assess these results, several statistical tests were applied, including the student-t and standard error. The results are summarized in Table 3, where A and B refer to a straight line best fit of the form $\sigma = A + B\mu$. The results indicate that the activity groupings are not sufficiently distinct from one another to justify distinguishing between them.

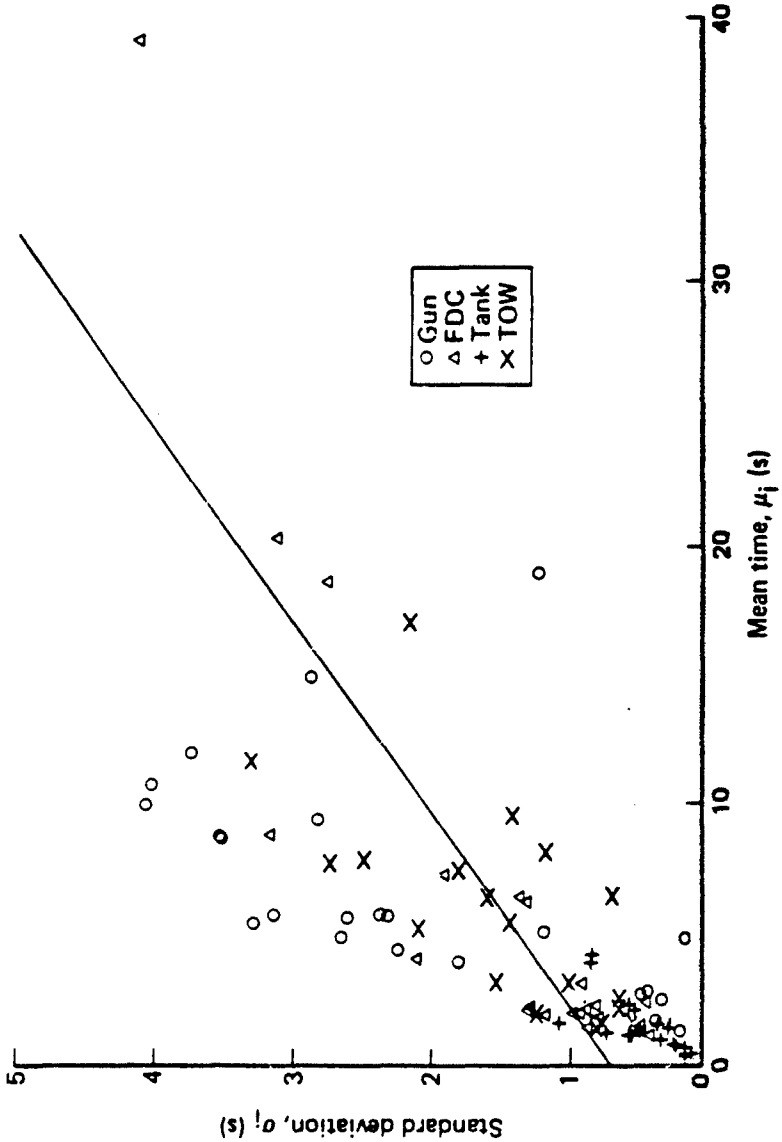
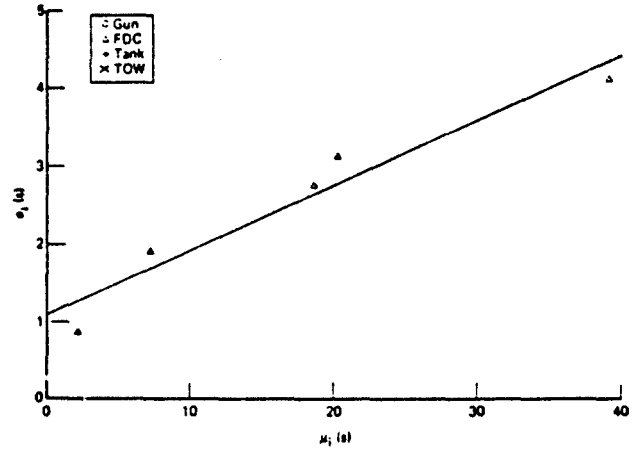
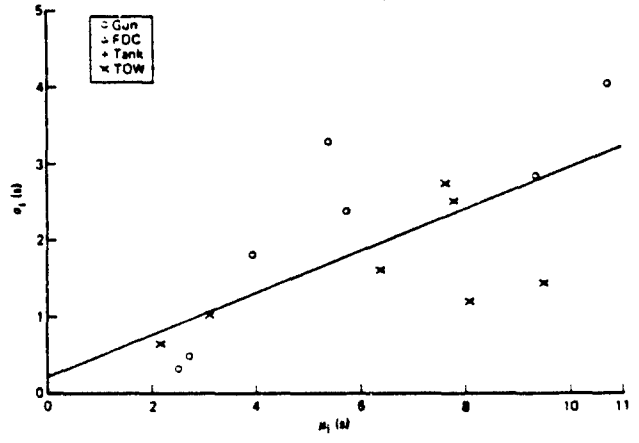



Figure 2. Scatter plot of σ versus μ for all tasks.

a. Cognitive.




b. Demanding.




c. Normal.

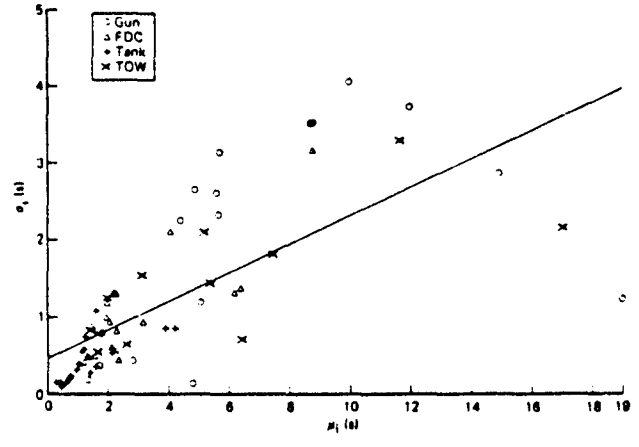



Figure 3. Scatter plot of σ versus μ by task group.

Table 3. Regression results.

| | Crew Type | Tasks | SD | A | B | SD(A) | SD(B) | COV(A,B) |
|---|---|---|---|---|---|---|---|---|
| 1 | Gun crew | 23 | 1.1702 | 1.0741 | 0.1589 | 0.4576 | 0.0572 | -0.0222 |
| 2 | FDC crew | 23 | 0.4979 | 0.7873 | 0.0999 | 0.1271 | 0.0120 | -0.0009 |
| 3 | Tank crews | 20 | 0.1982 | 0.1640 | 0.1943 | 0.0740 | 0.0427 | -0.0025 |
| 4 | TOW crew | 19 | 0.5916 | 0.7269 | 0.1312 | 0.2411 | 0.0344 | -0.0068 |

Standard Error and T-Statistics

| Comparisons | Intercept (A) | | | Slope (B) | | |
|---|---|---|---|---|---|---|
| | Standard Error | Student-T | DF | Standard Error | Student-T | DF |
| Gun crew/FDC crew | 0.0990 | 2.8957 | 44 | 0.0122 | 4.8362 | 44 |
| Gun crew/Tank crew | 0.0968 | 9.3975 | 41 | 0.0153 | 2.3204 | 41 |
| Gun crew/TOW crew | 0.1103 | 3.1476 | 40 | 0.0143 | 1.9345 | 40 |
| FDC crew/Tank crew | 0.0312 | 19.9523 | 41 | 0.0099 | 9.5576 | 41 |
| FDC crew/TOW crew | 0.0613 | 0.9845 | 40 | 0.0083 | 3.7845 | 40 |
| Tank crew/TOW crew | 0.0577 | 9.7523 | 37 | 0.0124 | 5.0963 | 37 |

| Stress Type | Tasks | SD | A | B | SD(A) | SD(B) | COV(A,B) |
|---|---|---|---|---|---|---|---|
| Cognitive | 5 | 0.3567 | 1.1004 | 0.0832 | 0.2702 | 0.0125 | -0.0027 |
| Demanding | 14 | 0.8310 | 0.2209 | 0.2725 | 0.5364 | 0.0804 | -0.0392 |
| Normal | 66 | 0.7443 | 0.4671 | 0.1859 | 0.1295 | 0.0231 | -0.0021 |
| All tasks | 85 | 0.8077 | 0.7029 | 0.1354 | 0.1170 | 0.0152 | -0.0012 |

Standard Error and T-Statistics

| Comparisons | Intercept (A) | | | Slope (B) | | |
|---|---|---|---|---|---|---|
| | Standard Error | Student-T | DF | Standard Error | Student-T | DF |
| Cognitive/Demanding | 0.1875 | 4.6909 | 17 | 0.0222 | 8.5278 | 17 |
| Cognitive/Normal | 0.1219 | 5.1957 | 69 | 0.0063 | 16.4060 | 69 |
| Cognitive/All tasks | 0.1215 | 3.2715 | 88 | 0.0058 | 8.9665 | 88 |
| Demanding/Normal | 0.1442 | 1.7071 | 78 | 0.0217 | 3.9950 | 78 |
| Demanding/All tasks | 0.1439 | 3.3492 | 97 | 0.0215 | 6.3651 | 97 |
| Normal/All tasks | 0.0204 | 11.5718 | 149 | 0.0033 | 15.3807 | 149 |

NOTE: DF = degrees of freedom.

Finally, Fig. 4 is a scatter plot of $\sigma_i^*$ versus $\mu_i^*$, where

$$\mu_i^* = \frac{1}{N} \sum_{j=1}^{N} \ln t_{ij} \quad , \tag{2a}$$

$$\sigma_i^* = \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} \left( \ln t_{ij} - \mu_i^* \right)^2} \quad , \tag{2b}$$

and where $j = 1,2,\ldots,N$ ranges over trials for task i, and the $t_{ij}$ are measured times. A best-fit, straight horizontal line was fit to this pattern, and we concluded that such a slope = 0 curve was as good a fit as any other. Thus, the algorithm for sampling for degraded times becomes:

> Sample random variables, $\tau$, from a normal distribution with mean, $\mu_i^* - \ln p$, and standard deviation $\sigma_i^*$; then, $t = \exp(\tau)$.

This is equivalent to sampling t from a lognormal distribution with mean,

$$\mu(p) = \mu(p=1)/p = \exp(\mu^* - \ln p + \sigma^{*2}/2) \quad , \tag{3a}$$

and standard deviation (SD),

$$\sigma(p) = \sqrt{e^{2(\mu^* - \ln p) + \sigma^{*2}} \left( e^{\sigma^{*2}} - 1 \right)} \quad , \tag{3b}$$

i.e.,

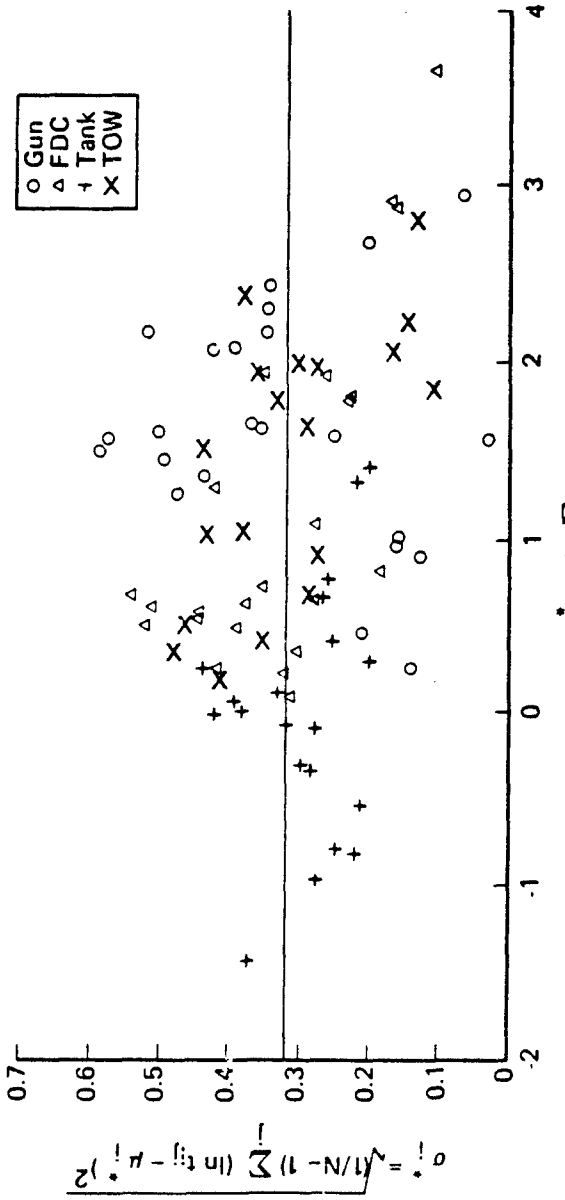



Figure 4. Final distribution scatter plot.

$$\sigma(p) = \sigma(p=1)\sqrt{e^{-2\ \ln\ p}} \qquad (3c)$$

$$= 1/p \cdot \sigma(p=1) \quad .$$

This is the desired relationship for $\sigma(\mu)$. Therefore, an alternative form of sampling for t, which is equivalent, is:

> Sample random variables, t, from a lognormal distribution with mean, $\mu(p=1)/p$, and standard deviation, $\sigma(p=1)/p$.

## SECTION 3
## DEVELOPING TASK DIAGRAMS

The decomposition of an engagement involving several interacting crewmembers into a specific set of modular tasks depends on the level of resolution required. The particular structures chosen for collecting the empirical data were designed to facilitate accurate timings between natural breakpoints in the action. This is illustrated by considering the empirical task lists summarized in Appendix A. Task 24 for the M60A3 tank crew commences immediately after the tank commander (TC) orders "backup." The full description states that this task consists of the driver backing up until the TC orders "stop," whereupon the driver stops and parks the tank. Here two different individuals are involved, and three distinct actions must be performed in sequence, i.e., an action by the driver, then an order from the TC, followed by a final action by the driver. For an accurate simulation in which the TC and driver may be in very different degradation states, the distinction between the three components of this "task" can be significant. A similar situation arises in several of the other empirical tasks.

As a consequence, many of the empirical tasks were subdivided into two or more simulation tasks for incorporation into the final task diagrams. This, in turn, necessitated distributing the mean task time and the associated variance among the subdivided tasks without altering their combined values. Although this could only be done by careful intuitive judgment, the net mean time and variance for the set, which must remain as measured, were preserved. Since for the original measurements these appeared as a single, continuous activity, the addition of detailed internal structure to this set of tasks had negligible effect.

The procedure for redistributing the variances among subdivided tasks results from requiring that three conditions be met. For an empirical task with mean time $t$, the subtasks are assigned mean times such that

$$t_a + t_b = t \ . \qquad (4)$$

Assuming that the tasks are independent, the standard deviations are then constrained such that

$$\frac{\sigma_a}{\sigma_b} = \frac{t_a}{t_b} \qquad \text{and} \qquad \sigma_a^2 + \sigma_b^2 = \sigma^2 \ . \qquad (5)$$

The standard deviations for the subtasks are then given by

$$\sigma_b' = \frac{\sigma'}{\sqrt{1 + (t_a/t_b)^2}} \qquad \text{and} \qquad \sigma_a' = \sigma' - \sigma_b' \ . \qquad (6)$$

The resulting input values used for the simulation are tabulated in Appendix B, along with the final task lists for the four crew types. These correspond to the task diagrams in Appendix C. The column marked "data tasks" contains the original empirical task number from the measurement data, and is followed by a letter (a, b,....etc.) if the task was subdivided. Empirical tasks 21 through 24 for the M109 gun crew were in fact copies of tasks 8 through 11, i.e., no 'independent' measurements were taken for the repeat of the loading operations.

## SECTION 4

## MONTE CARLO SIMULATION OF CREW PERFORMANCE

The CREW-III Monte Carlo simulation code [Dore, 1986] was utilized to predict the mean overall engagement time for each crew type. This involved computing 100 independent histories (realizations) of the simulated engagement, resulting in a predicted mean time for each of the types of engagement. The reconciliations of the overall engagement times obtained from this simulation with the measured mean times are shown in Table 4. Since some of the simulated engagements contained additional tasks not included in the original, measured engagements, correction terms were needed to make a meaningful comparison between the predicted and measured times. For example, the initial six tasks for the tank crew, during which the tank commander and gunner are searching for a target, were included to conform to the earlier IDP scenario. These tasks consume an average of about 1.7 s which were not included in the empirical measurements.

Corrections were also required for the measured, empirical overall task times for the tank crew. In discussing the comparison of COFT simulator and field exercise task time measurements, Mover and Lam [1987] observed: "Comparison of the COFT generated data with the loader shows that the loaders were slower. However, it would appear that the loaders would have added only about a one second delay to the crews ability to fire the second round."

Then, a few sentences later, in reference to timing the drivers, Mover and Lam [1987] state: "...the time to back up the tank appears to be twice as long as expected based on the TC/G performance in the COFT. Due to the restricted cues in the COFT it is possible that these TC's were stopping their simulated tanks sooner than they should have." Based upon these comments, an additional 2.0 s were added to account for the loaders and an additional 1.418.2 = 0.709 s of backup time for the drivers.

Table 4. Reconciliation of overall engagement times.

| Crew Type | CREW-III Results | | | Empirical Data | | | |
|---|---|---|---|---|---|---|---|
| | Raw Time | Correction | Net | Raw Time[a] | Correction | Net | Percent |
| Gun | 103.18 | | 103.18 | 116.43 | | 116.43 | -12.8 |
| FDC | 93.38 | | 93.38 | 69.69 | +6.86[b] | 76.55 | +18.0 |
| Tank | 28.06 | -1.70[c] | 26.36 | 22.79 | +2.71[d] | 25.50 | +3.26 |
| ITV-TOW | 157.82 | -28.00[e] | 129.82 | 141.57 | | 141.57 | -9.05 |

[a]Empirical values for total engagement time reflect the less than ideal conditions under which field data measurements were gathered.
[b]Tasks 11 through 14 were removed.
[c]Initial target acquisition.
[d]Loader and driver too fast in COFT.
[e]Driver tasks.

The right-hand column of Table 4 summarizes the relative accuracy with which the Monte Carlo simulation reproduces the empirical results. Except for the FDC crew, for which the empirical "measurements" are very doubtful, the agreement is satisfactory.

The CREW-III code was then applied to selected combinations of degraded crewmembers. The degradation states chosen and the final mean engagement times found are summarized in Appendix D. For some crew types, additional points were included to ensure that the entire four-space, i.e., four crewmembers, was sufficiently represented.

## SECTION 5
## FOUR-DIMENSIONAL FUNCTIONAL FIT

A simplified expression for overall crew performance as a function of the performance levels of the individual crewmembers was derived as follows: Consider a crew consisting of four crewmembers, each responsible for a specific subset of the full set of tasks making up the engagement. Assuming that all tasks are performed sequentially, the total time for the engagement would simply be the sum of the time taken by each crewmember. Let $T_i$ be the sum of the normal (undegraded) times for the tasks of crewmember $i$, $i = 1, 2, \ldots, 4$, so that the total mission time is

$$T_{tot} = \sum_{i=1}^{4} T_i \quad . \tag{7a}$$

The performance of a crewmember is defined as $p_i = T_i/t_i$, where $t_i$ is the longer time required to accomplish the same set of tasks when the crewmember is degraded. Thus, $p_i$ is always between 0 and 1. Similarly, the overall crew performance is given by $P = T_{tot}/t_{tot}$, where $t_{tot} = \sum t_i$. It then follows that

$$P = \frac{1}{\sum \frac{\alpha_i}{p_i}} \quad , \tag{7b}$$

where

$$\alpha_i = T_i / T_{tot} \quad . \tag{8}$$

Equation (7b) shows that each of the crewmember performances is reciprocally weighted by his fraction of the total mission time when all are undegraded. The assumption of a series of sequential tasks used to derive this expression is true only specifically for the ITV-TOW crew. The other three crew types require the crewmembers to perform tasks in a series-parallel fashion, where at various times during the engagement two or more tasks are performed simultaneously. However, by using Eq. (7b) as a guide, the Monte Carlo results for these other three crew types were found to be remarkably well fit by a generalized form of Eq. (7b).

$$P = \frac{1}{\sum_{i=1}^{4} \left( \frac{\alpha_i}{p_i} \right)^{\beta_i}} \quad . \tag{9}$$

The $\beta$ exponents allow four more degrees of freedom to account for interaction effects between crewmembers. Both the $\alpha$'s and $\beta$'s were determined from a simplex algorithm which mimimized the standard error over all points. The starting guesses for the $\alpha$'s were determined from Eq. (8) and the $\beta$'s were initialized to 1.0; in all cases, the results converged rapidly to a distinct minimum. The resulting values are tabulated in Table 5, along with the correspondence between the indices and crewmember positions.

The CREW-III simulation for the ITV-TOW crew incorporated only three crewmembers: squad leader, gunner, and loader. The fourth crewmember, the driver, was not included since the empirical data for the ITV-TOW crew was taken without a driver present. As already mentioned, the ITV-TOW tasks are performed sequentially, and therefore the $\beta$'s are all 1.0. The accuracy of the CREW-III simulation and subsequent fit to Eq. (9) is evident by noting the near unity values of the $\beta$'s for the ITV-TOW crew in Table 5.

The previous IDP study did include a driver, whose total task time was normally 28.0 s for maneuvering and parking at the launch site prior to the other crewmembers beginning their tasks. For both

Table 5. Fit parameters.

| Parameter | Gun Crew | FDC Crew | Tank Crew | TOW Crew |
|---|---|---|---|---|
| $\alpha_1$ | 0.073953 | 0.23466 | 0.24249 | 0.13111 |
| $\alpha_2$ | 0.074018 | 0.37234 | 0.22197 | 0.47759 |
| $\alpha_3$ | 0.24954 | 0.44990 | 0.31879 | 0.17742 |
| $\alpha_4$ | 0.59286 | -- | 0.31198 | 0.21546 |
| $\beta_1$ | 1.2502 | 1.6017 | 0.98866 | 1.0389 |
| $\beta_2$ | 0.67995 | 0.81154 | 1.1181 | 1.0137 |
| $\beta_3$ | 1.0037 | 0.98212 | 1.2815 | 1.0000 |
| $\beta_4$ | 1.1755 | -- | 1.0046 | 0.96201 |

| Crew Type | Crewmember Index (i) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| M109 howitzer gun crew | Chief of Section | Gunner | Assistant Gunner | No. 1 Cannoneer |
| Fire Direction center (FDC) | Fire Direction Officer | Computer | Horizontal Control Operator | -- |
| M60A3 tank crew | Tank Commander | Gunner | Loader | Driver |
| M901 ITV-TOW crew | Squad Leader | Gunner | Driver | Loader |

consistency with the previous IDP study and because an actual ITV-TOW crew includes a driver, a modification was made to the results to incorporate the effects of a driver into the results.

This modification consisted of adding an additional 28 s to the engagement time for vehicle motion with an undegraded driver. Then, if $T_{tot} = 129.824$ s is the total engagement time for the three man crew, the new total time will be $T'_{tot} = T_{tot} + 28 = 157.824$ s. Also, the total engagement time with degraded crewmembers becomes

$$T' = T + 28/p_D, \quad \text{where} \quad T = T_{tot} \cdot \sum_{i=1}^{3} \left(\frac{\alpha_i}{p_i}\right)^{\beta_i} \tag{10}$$

is the total engagement time for the three-man crew, and $p_D$ is the performance level of the driver. Thus,

$$\frac{1}{P'} = \frac{T'}{T'_{tot}} = \frac{T_{tot}}{T_{tot} + 28} \cdot \sum_{i=1}^{3} \left(\frac{\alpha_i}{p_i}\right)^{\beta_i} + \frac{28}{T_{tot} + 28} \left(\frac{1}{p_D}\right)$$

$$= \frac{T_{tot}}{T_{tot} + 28} \left[ \sum_{i=1}^{3} \left(\frac{\alpha_i}{p_i}\right)^{\beta_i} + \left(\frac{28/T_{tot}}{p_D}\right) \right], \tag{11}$$

so we find that

$$P' = \frac{K}{\sum_{i=1}^{4} \left(\frac{\alpha_i}{p_i}\right)^{\beta_i}}, \quad \text{with} \quad \alpha_4 = 28/T_{tot}, \quad \beta_4 = 1, \quad p_4 = p_D, \text{ and } K = (T_{tot} + 28)/T_{tot}. \tag{12}$$

This is the same form as Eq. (9) except for the constant, K, which is easily removed by incorporating it into the $\alpha$'s.

Comparisons of the simulation results and the values predicted by Eq. (9) are included in Appendix D. Appendix E contains a representative set of plots of numerous planes in the four-space for each

crew type. Also included on these plots are the points to which they were fit.

## SECTION 6
## DOSE AND TIME DEPENDENCE

The crew performance formula (Eq. 9) is suitable for many applications involving degraded crewmembers. One such application is the Army Unit Resiliancy Analysis (AURA) code at BRL. AURA allows reconstitution of a tactical unit with any mix of degraded personnel, regardless of the underlying cause of the degradation. For instance, the limitations on crew performance caused by wearing mission-oriented protection posture (MOPP) gear in a chemical attack environment can be simulated by applying Eq. (9).

Other battlefield simulation codes are primarily concerned with effects on a tactical unit directly, rather than indirectly through the performance of the crewmembers. One such is the JANUS conflict simulation code at LLNL. One requirement of JANUS is to simulate the time-dependent performance of combat crew units after acute exposure to an intermediate dose of ionizing radiation from a tactical nuclear weapon detonation.

Providing such a model extends naturally from the earlier IDP study [Anno, Wilson, and Dore, 1983] in which the performance of individuals was characterized for acute exposure as a function of dose and time. A given external dose to a unit (e.g., a tank) is reduced by an appropriate shielding factor for each crew position, resulting in a dose to each crewmember. The results of the IDP study were then applied to find the performance level of each crewmember at some later time, and Eq. 9 was then applied to yield the overall unit performance at that time.

A modification of the above procedure is necessary because not all individuals develop any or all of the disabling symptoms of acute radiation sickness which are the cause of degraded performance. The crewmember performance results reported in the IDP study are conditionally dependent upon an individual having expressed these symptoms, and for those individuals who are not affected there is no degradation, i.e., their performance level is 1.0. This individual variability in response to radiation exposure was accounted for by

finding an expected performance for the unit by combining the sixteen possible situations of four crewmembers, each either expressing or not expressing symptoms, weighted by the incidence fractions for developing symptoms.

Estimates of incidence fractions for each of the major symptoms (e.g. nausea, vomiting, fatigability) of acute exposure to ionizing radiation have been determined as a function of dose [Anno, Wilson, and Baum, 1985]. While these incidence fractions are specific to each type of symptom, they are highly correlated, and the actual performance degradation of an individual is usually dominated by the initial and most severe symptom developed. This allows an overall incidence curve to be determined by assuming an individual develops the characteristic degradation with the onset of any one symptom. Curves of incidence fraction versus dose for the major symptoms of radiation sickness are plotted in Fig. 5 based on both lognormal and logistic forms of the distributions with dose. The overall incidence curve consists of the leftmost of these symptom curves at any incidence level. The resulting three-part formula is given in Table 6.

The expected performances were then calculated for the four crew types. First the protection factors from Table 7 were applied to reduce the exposure external to the vehicle by an amount appropriate for inside the type of vehicle. Note that only the M60A3 tank varied in density sufficiently to afford different degrees of radiation protection dependent upon where in the vehicle the crewmember was located. The weights and performances of each crewmember were then calculated for all 16 combinations of symptom incidence and then combined together with Eq. (9), in the manner given as follows: Let $D_o$ be an acute dose of ionizing radiation external to the vehicle which occurs at time $t = 0$. Then, for the $i$th crewmember $(i = 1, 2, \ldots, 4)$, define:

$PF_i$ = protection factor,

$D_i = D_o/PF_i$,

$p_i(D_i, t)$ = conditional performance level of $i$th crewmember,

$f_i(D_i)$ = probability that symptoms are expressed by $i$th crewmember.

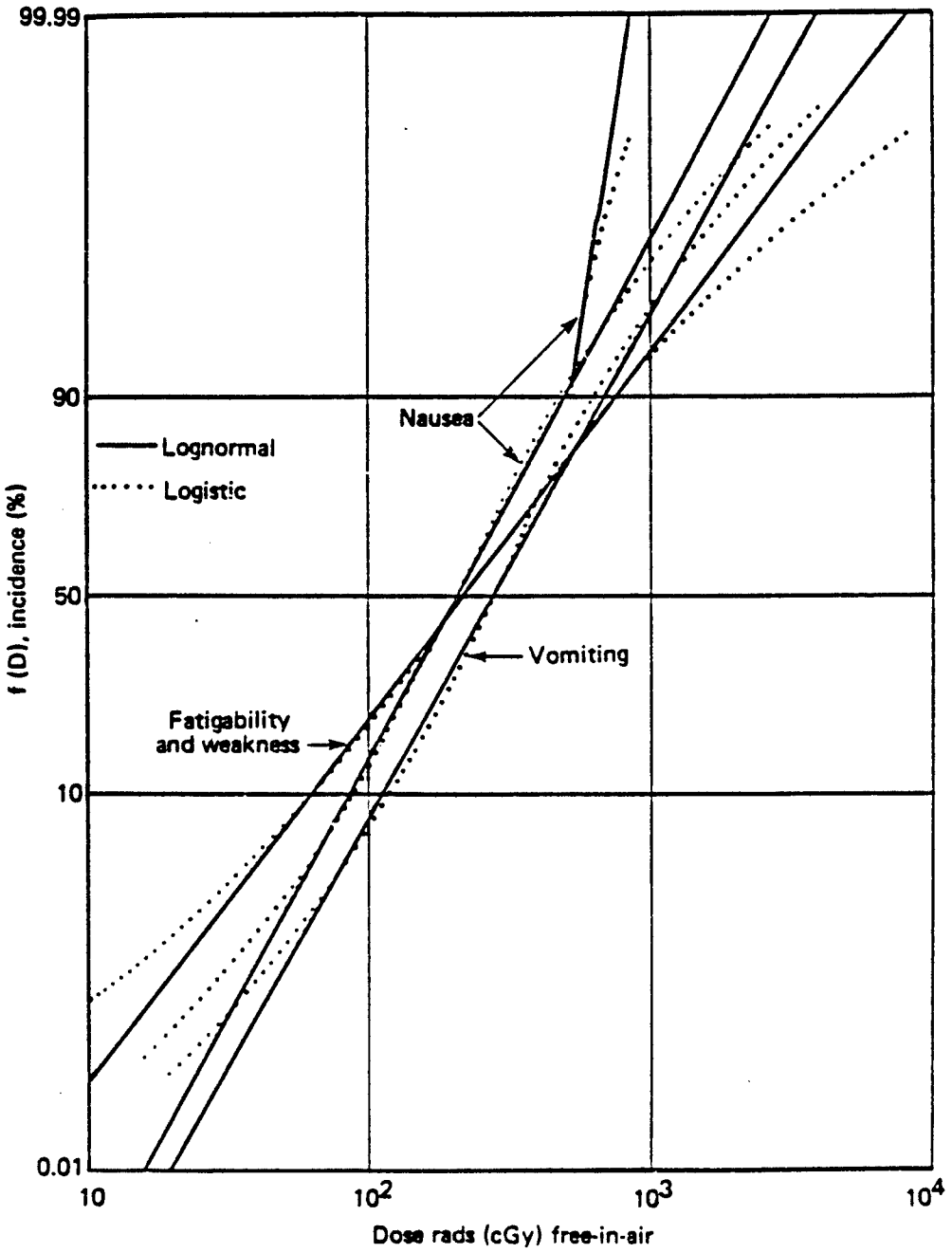



Figure 5. Symptom incidence.

Table 6. Symptom incidence.

| Principal Symptom | Dose Range (rads) | a | b |
|---|---|---|---|
| Fatigability and Weakness | 0 - 185 | 8.75 | 1.63 |
| Nausea | 185 - 530 | 12.2 | 2.30 |
| Nausea | > 530 | 49.8 | 8.27 |

Symptom incidence:

$$f(D) = \frac{1}{1 - e^{a - b \ln D}} .$$

Table 7. Radiation shielding protection factors.

| Crew and Position | Factor |
|---|---|
| M109 howitzer gun crew | |
| Chief of section | 1.3 |
| Gunner | 1.3 |
| Assistant gunner | 1.3 |
| No. 1 cannoneer | 1.3 |
| FDC | |
| Fire direction officer | 1.0 |
| Computer | 1.0 |
| Horizontal control operator | 1.0 |
| M60A3 tank crew | |
| Tank commander | 1.4 |
| Gunner | 2.0 |
| Loader | 1.9 |
| Driver | 3.8 |
| M901 ITV-TOW crew | |
| Squad leader | 1.4 |
| Gunner | 1.4 |
| Driver | 1.4 |
| Loader | 1.4 |

The 16 combinations can then be represented by taking:

$$0 \Rightarrow \text{Unaffected: } p_i^* = 1.0, \qquad w_i = 1 - f_i \ ,$$
$$1 \Rightarrow \text{Affected: } p_i^* = p_i, \qquad w_i = f_i \ ,$$

and arranging all combinations as a binary series, i.e.

| Case n: | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crew member | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

The weight assigned to the $n$th case is then given by

$$W_n = \prod_{i=1}^{4} w_i \ , \quad \text{where} \quad \sum_{n=0}^{15} W_n = 1 \ , \tag{13}$$

and the crew performance (given by Eq. 9) for case n is

$$Q_n = \frac{1}{\sum_{i=1}^{4} \left( \frac{\alpha_i}{p_i^*} \right)^{\beta_i}} \ . \tag{14}$$

The combined average crew performance is then given by

$$P(D_o, t) = \sum_{n=0}^{15} W_n Q_n \ . \tag{15}$$

The unit performances which result from the calculations given above are tabulated in Appendix F as an evenly spaced grid of points in log dose (external to the unit) and log time. The extent of this table is identical to that of the earlier IDP study, and the general

appearance of the surface plots (Appendices G and H), not surprisingly, is very similar to those for individual crewmembers in the IDP study.

## SECTION 7
## DISCUSSION

The methodology followed in this study to develop crew unit performance demonstrates that a fairly complex procedure, such as that required for modeling the collective actions of individual crewmembers, can often be replaced by a fairly simple yet effective algorithm. This result embodies all the appropriate details and has the obvious advantage of reducing computation, especially for utilization in larger scale battlefield simulations such as AURA, which involve a great amount of other computations. Also, the algorithm developed in this study provides the flexibility that enables crew unit performance estimates to be made for arbitrary levels of degraded states distributed among the various crewmembers, regardless of the cause.

The methodology, as we demonstrate in this study, can also be extended to specifically address crew unit performance where the performance of individual crewmembers may be impaired by the effects of ionizing radiation exposure. Here the conditional crew unit performance algorithm (as developed for AURA) is modified by taking into account both individual variability in response to radiation effects as well as extra- and intravehicular environmental dose levels among the crewmembers.

Crew unit performance data generated in this study pertains to fixed short combat engagement scenarios for the combat crews evaluated along a post-acute-exposure time frame (up to 6 weeks) for extravehicular environmental dose levels. These data provide input to other larger-scale battlefield simulation programs such as JANUS, which require prepackaged radiation effects embedded in crew performance values. These performance values are weight-averaged over the sixteen possible combinations of sickness states of four crewmembers.

However, based on the procedure we give to obtain these average crew unit performance values, discrete component crew performance estimates and their associated probabilities can be generated as

desired for arbitrary dose and time, utilizing the shielding factors and symptom incidence data presented in this report and the previously developed dose-time individual crewmember performance data [Anno, Wilson, and Dore, 1983]. This discrete probabalistic crew unit performance data, for example, would be more appropriate for battlefield simulations which treat combat crew unit performance stochastically.

Aside from application to larger-scale battlefield simulation or gaming codes, the graphical presentations of crew unit performance can be useful for training and education purposes in developing tactical guidelines. In this regard, some general observations can be made and caveats noted.

Crew unit performance generally follows the level of performance of the individual crewmembers over dose and time, although not necessarily in a linear fashion. For example, overall crew performance is not greatly affected by any one crewmember who may be significantly degraded compared to the others until that crewmember's performance level approaches around 50 percent. A plot of crew unit performance against decreasing performance values of one of the crewmembers, all others fixed, would initially appear relatively shallow and then rapidly turn down with smaller values of the individual's performance.

Task time variability, derived from field measurements according to a detailed characterization of subtasks that comprise a combat encounter scenario, comes from a population of participants in a normal state of health. Since it is impossible to acquire the corresponding measure of variability from a population of individuals impaired by the effects of ionizing radiation, we must assume that the standard deviation of task-performance time varies monotonically with the increased mean task-performance time expected when an individual is impaired by the effects of radiation. The assumed inverse performance relationship is consistent with the results from the statistical analysis of the field measurement data.

Finally, the crew unit performance values are all based on short but intense actions that take place during the tactical combat engagements modeled. In this regard, we are uncertain how applicable these performance values are to other combat crew scenarios where the action

levels are not as intense or where the duration of performance extends over much longer periods, for example, as in logistic or support operations, road marches, or other activities where protracted fatigue becomes a factor.

## SECTION 8

## LIST OF REFERENCES


Anno, G. H., D. B. Wilson, and S. J. Baum, *Severity Levels and Symptom Complexes for Acute Radiation Sickness: Description and Quantification*, Pacific-Sierra Research Corporation, Report 1597, 30 November 1985.

Anno, G. H., D. B. Wilson, and M. A. Dore, *Acute Radiation Effects on Individual Crewmember Performance*, Pacific-Sierra Research Corporation, Note 572, October 1983.

Blumenthal, D. K., et al., *An Analysis of a Massed Versus a Dispersed Attacking Ground Force in Close Combat*, Lawrence Livermore National Laboratory, Livermore, California, UCID-20010, 31 January 1984.

Dore, M. A., *CREW III User's Guide*, Pacific-Sierra Research Corporation, Report 1660, 1 September 1986.

Klopcic, J. T. and L. K. Roach, *An Introduction to the Use of the Army Unit Resiliency Analysis (AURA) Methodology*, Vol. I, U.S. Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, Memorandum Report BRL-MR-3384, September 1984.

Mover, M. J., and S. Lam, *M60A3 Combat Tank Data*, Science Applications International Corporation, unpublished, forwarded in a letter dated 6 March 1987 to R. W. Young, Defense Nuclear Agency, Washington, DC.

Mover, M. J., T. K. O'Donoghue, and M. L. Feinberg, *The Final Report of the Task Timeline Analysis Project*, Science Applications International Corporation, La Jolla, California, Report 1-262-03-509-02, 12 September 1984.

## APPENDIX A

## TASK DESCRIPTION FOR EMPIRICAL DATA

Tables 8 through 11 detail the empirical tasks performed by the members of the four crews. The mean and standard deviation for each empirical task is included.

Table 8. Empirical task descriptions for gun crew.

| Task No. | Description of Actions | Simulator (S) Live Fire (L) | Crewmember | Mean | SD |
|---|---|---|---|---|---|
| 1 | Issues, receives and relays fire mission data | S | Chief of section | 18.99 | 1.247 |
| 2 | Loads projectile and prepares to ram | L | No. 1 cannoneer | 5.74 | 2.990 |
| 3 | Laying for deflection | S | Gunner | 9.94 | 4.516 |
| 4 | Laying for quadrant | S | Assistant gunner | 11.96 | 3.725 |
| 5 | Laying for deflection and quadrant[a] | S | Gunner and assistant gunner | 14.91 | 3.427 |
| 6 | Operates and retracts rammer | L | No. 1 cannoneer | 5.08 | 1.223 |
| 7 | Loading propellant and closing breachblock[a] | L | No. 1 cannoneer | 10.72 | 4.343 |
| 8 | Stows rammer and tray | S | No. 1 cannoneer | 2.72 | 0.718 |
| 9 | Loads propellant charge | S | No. 1 cannoneer | 2.82 | 0.509 |
| 10 | Closes breachblock | S | No. 1 cannoneer | 2.51 | 0.443 |
| 11 | Checks lay for deflection and quadrant | S | Chief of section | 4.81 | 0.143 |
| 12 | Primes cannon and attaches lanyard | L | No. 1 cannoneer | 4.86 | 2.580 |
| 13 | Fires weapon, recovers and detaches lanyard | L | No. 1 cannoneer | 5.70 | 3.128 |

[a]Task 5 is equivalent to tasks 3 and 4 combined; similarly, task 7 is equivalent to tasks 8 through 11, and task 20 is equivalent to tasks 21 through 24.

Table 8. Empirical task descriptions for gun crew (continued).

| Task No. | Description of Actions | Simulator (S) Live Fire (L) | Crewmember | Mean | SD |
|---|---|---|---|---|---|
| 14 | Swabs bore and checks clear | L | No. 1 cannoneer | 8.75 | 3.553 |
| 15 | Positions loading tray and rammer | L | No. 1 cannoneer | 3.94 | 1.811 |
| 16 | Loads projectile and prepares to ram | L | No. 1 cannoneer | 5.39 | 3.368 |
| 17 | Lays for quadrant | S | Assistant gunner | 1.34 | 0.345 |
| 18 | Lays for Deflection | S | Gunner | 1.72 | 0.689 |
| 19 | Operates & retracts rammer | L | No. 1 cannoneer | 5.67 | 2.329 |
| 20 | Loads propellant and closes breachblock[a] | L | No. 1 cannoneer | 9.36 | 3.099 |
| 21 | Stows rammer and tray | | No. 1 cannoneer | (2.72 | 0.718)[b] |
| 22 | Loads propellant charge | S | No. 1 cannoneer | (2.82 | 0.509)[b] |
| 23 | Closes breachblock | S | No. 1 cannoneer | (2.51 | 0.443)[b] |
| 24 | Checks lay for deflection and quadrant | S | Chief of section | (4.81 | 0.143)[b] |
| 25 | Primes weapon and attaches lanyard | L | No. 1 cannoneer | 4.40 | 2.302 |
| 26 | Fires weapon, recovers and detaches lanyard | L | No. 1 cannoneer | 5.59 | 2.661 |
| 27 | Swabs bore and checks clear | L | No. 1 cannoneer | 8.67 | 3.552 |

[a]Task 5 is equivalent to tasks 3 and 4 combined; similarly, task 7 is equivalent to tasks 8 through 11, and task 20 is equivalent to tasks 21 through 24.

[b]Tasks 21 through 24 were not measured independently, but are copies of tasks 8 through 11.

Table 9. Empirical task descriptions for FDC crew.

| Task No. | Description of Actions | Crewmember | Mean | SD |
|---|---|---|---|---|
| 1 | Issues call for fire | (Observer) | 2.35 | 0.547 |
| 2 | Receives and reads back call for fire | Fire direction officer | 2.12 | 0.915 |
| 3 | Identifies registration point | (Observer) | 3.16 | 1.080 |
| 4 | Receives and reads back registration point to be used | Fire direction officer | 2.26 | 1.202 |
| 5 | Announces target coordinates | (Observer) | 6.21 | 1.509 |
| 6 | Receives and reads back target coordinates | Fire direction officer | 7.22 | 2.343 |
| 7 | Describes target | (Observer) | 4.06 | 2.058 |
| 8 | Receives and reads back target description | Fire direction officer | 2.03 | 1.085 |
| 9 | Issues fire order | Fire direction officer | 2.16 | 1.292 |
| 10 | Determines and transmits the message to observer | Fire direction officer | 1.98 | 1.217 |
| 11 | Transmits "fire mission" to battery | Computer | 1.95 | 1.079 |
| 12 | Receives and reads back "fire mission" | (Battery) | 1.33 | 0.476 |
| 13 | Transmits fire order to battery | Computer | 1.52 | 0.548 |
| 14 | Receives and reads back fire orders to computer | (Battery) | 1.81 | 0.859 |
| 15 | Plots target and announces chart range | Horizontal control operator | 39.14 | 5.312 |
| 16 | Receives and reads back target range | Computer | 2.28 | 0.963 |

Table 9. Empirical task descriptions for FDC crew (continued).

| Task No. | Description of Actions | Crewmember | Mean | SD |
|---|---|---|---|---|
| 17 | Announces chart deflection | Horizontal control operator | 6.39 | 1.717 |
| 18 | Receives and reads back target range | Computer | 2.18 | 1.341 |
| 19 | Computes firing data, converts to fire commands, and transmits deflection to battery | Computer | 20.32 | 9.372 |
| 20 | Receives and reads back deflection | (Battery) | 1.46 | 0.922 |
| 21 | Computes site and announces when requested by computer | Fire direction officer | 18.64 | 6.343 |
| 22 | Computes and transmits quadrant to battery | Computer | 8.76 | 5.806 |
| 23 | Receives and reads back quadrant | (Battery) | 1.17 | 0.460 |

Table 10. Empirical task descriptions for tank crew.

| Task No. | Description of Actions | Simulator (S) Live Fire (L) | Crewmember | Mean | SD |
|---|---|---|---|---|---|
| 1 | Issues initial fire command, traverse turret | S | Tank commander | 0.274 | 0.141 |
| 2 | Arm main gun | L | Loader | 1.916 | -- |
| 3 | Main gun switch to on, index ammunition, identify target | S | Gunner | 1.231 | 0.738 |
| 4 | Pull next round | L | Loader | 5.745 | -- |
| 5 | Aim main gun, lase range | S | Gunner | 1.184 | 0.575 |
| 6 | Confirms range | S | Tank commander | 1.142 | 0.549 |
| 7 | Commands driver forward and gunner to guide driver | S | Tank commander | 0.756 | 0.232 |
| 8 | Drive tank forward and stop | L | Driver | 3.894 | 0.851 |
| 9 | Guide driver into firing position | S | Gunner | 2.323 | 0.572 |
| 10 | Verify hostile target and range; command fire | S | Tank commander | 2.127 | 0.523 |
| 11 | Final lay, alerts crew | S | Gunner | 1.288 | 0.485 |
| 12 | Pull trigger | S | Gunner | 1.034 | 0.388 |
| 13 | Reload, arm main gun, and pull next round | L | Loader | 11.027 | -- |
| 14 | Observes round, reports impact | S | Tank commander | 1.581 | 0.354 |
| 15 | Issues order to reengage | S | Tank commander | 0.480 | 0.140 |
| 16 | Re-lay main gun, lase range | S | Gunner | 0.968 | 0.320 |

Table 10. Empirical task descriptions for tank crew (continued).

| Task No. | Description of Actions | Simulator (S) Live Fire (L) | Crewmember | Mean | SD |
|---|---|---|---|---|---|
| 17 | Verify range to target, commands fire | S | Tank commander | 1.601 | 1.085 |
| 18 | Final lay, alerts crew | S | Gunner | 0.610 | 0.145 |
| 19 | Pulls trigger | S | Gunner | 0.747 | 0.209 |
| 20 | Reload, select next round | L | Loader | 9.544 | -- |
| 21 | Observes round, report impact | S | Tank commander | 1.412 | 0.274 |
| 22 | Commands cease fire | S | Tank commander | 0.401 | 0.139 |
| 23 | Commands driver to return to defilade | S | Tank commander | 0.453 | 0.100 |
| 24 | Return tank to defilade and stop | L | Driver | 4.207 | 0.849 |

Table 11. Empirical task descriptions for ITV-TOW crew.

| Task No. | Description of Actions | Crewmember | Mean | SD |
|---|---|---|---|---|
| 1 | Alerts crew, issues elements of initial fire command | Squad Leader | 5.32 | 0.029 |
| 2 | Erect launcher | Gunner | 6.36 | 0.594 |
| 3 | Slews turret to track first target | Gunner | 11.29 | 1.845 |
| 4 | Arming left missile | Squad leader and gunner | 2.51 | 0.011 |
| 5 | Issues fire order | Squad leader | 2.02 | 0.597 |
| 6 | Tracks missile to target and announces results | Gunner | 19.37[a] | 0.843 |
| 7 | Terminates 1st firing sequence, issues subsequent fire commands | Squad leader | 7.91 | 0.396 |
| 8 | Traverses turret to track second target | Gunner | 4.80 | 1.679 |
| 9 | Arming right missile | Squad leader and gunner | 1.46 | 0.123 |
| 10 | Issues fire order | Squad leader | 1.80 | 0.763 |
| 11 | Tracks missile to target, and announces results | Gunner | 18.13[a] | 0.961 |
| 12 | Terminates action, orders reloading | Squad leader | 2.17 | 0.639 |
| 13 | Preparation for reload | Gunner and loader | 16.25 | 2.484 |
| 14 | Unloads left launch container | Loader | 3.22 | 0.957 |

[a]Includes flight time.

Table 11. Empirical task descriptions for ITV-TOW crew (continued).

| Task No. | Description of Actions | Crewmember | Mean | SD |
|---|---|---|---|---|
| 15 | Loads left launcher | Loader | 7.61 | 1.791 |
| 16 | Unloads-ejects right launch container | Loader | 2.06 | 0.381 |
| 17 | Loads right launcher from ready rack | Loader | 8.12 | 1.281 |
| 18 | Closes cargo hatch | Loader | 3.24 | 0.981 |
| 19 | Rearranges ready rack | Loader | 6.39 | 0.778 |

## APPENDIX B
## INPUT DATA

Data for the gun, FDC, tank, and ITV-TOW crews as input to the CREW 111 code are presented in Tables 12 through 15. The data are input exactly as shown in the tables.

Table 12. Input data for gun crew.

| Task No. | Description | Data Task[a] | Task Type | Mean (sec) | SD (sec) | Crewmember | Precursor Task(s) |
|---|---|---|---|---|---|---|---|
| 1 | START | -- | | 0.0 | 0.0 | -- | -- |
| 2 | AN:MISSION&DEFL. | 1A | | 15.99 | 1.226 | C.SECT. | 1 |
| 3 | AN: QUADRANT | 1B | | 3.00 | 0.230 | C.SECT. | 2 |
| 4 | LOAD PROJECTILE | 2A | P | 4.74 | 2.926 | NO. 1 C. | 3 |
| 5 | ROTATE CYLINDER | 2B | P | 1.00 | 0.617 | NO. 1 C. | 3 4 |
| 6 | LAY FOR DEFL. | 3A | | 8.44 | 4.446 | GUNNER | 2 |
| 7 | RECHECK SIGHT | 3B | | 1.50 | 0.790 | GUNNER | 6 8 |
| 8 | LAY FOR QUAD. | 4 | | 11.96 | 3.725 | AST.GNR. | 3 |
| 9 | CYCLE RAMMER | 6 | | 5.08 | 1.223 | NO. 1 C. | 5 |
| 10 | STOW RAM & TRAY | 8 | P | 2.72 | 0.718 | NO. 1 C. | 9 |
| 11 | LOAD PROPELLANT | 9 | | 2.82 | 0.509 | NO. 1 C. | 10 |
| 12 | CLOSE BREACH | 10 | P | 2.51 | 0.443 | NO. 1 C. | 11 |
| 13 | CHECK AIM | 11 | | 4.81 | 0.143 | C.SECT. | 7 9 |
| 14 | PRIME | 12 | | 4.86 | 2.580 | NO. 1 C. | 12 13 |
| 15 | FIRE | 13 | | 5.70 | 3.128 | NO. 1 C. | 14 |
| 16 | RECOIL | -- | | 1.00 | 0.0 | -- | 15 |
| 17 | SWAB BORE | 14 | | 8.75 | 3.553 | NO. 1 C. | 16 |
| 18 | AN: NEXT | 15A | | 1.00 | 0.583 | C.SECT. | 17 |
| 19 | POS'N TRAY & RAM | 15B | P | 3.94 | 1.811 | NO. 1 C. | 18 |
| 20 | AN: QUAD | 16A | | 1.00 | 0.748 | C.SECT. | 18 |
| 21 | LAY FOR QUAD | 17 | | 1.34 | 0.345 | AST.GNR. | 20 |
| 22 | LAY FOR DEFL | 18 | | 1.72 | 0.689 | GUNNER | 21 |
| 23 | LOAD PROJECTILE | 16B | P | 5.39 | 3.368 | NO. 1 C. | 19 20 |
| 24 | CYCLE RAMMER | 19 | | 5.67 | 2.329 | NO. 1 C. | 23 |
| 25 | STOW RAM & TRAY | (8/21) | P | 2.72 | 0.718 | NO. 1 C. | 24 |
| 26 | LOAD PROPELLANT | (9/22) | | 2.82 | 0.509 | NO. 1 C. | 25 |
| 27 | CLOSE BREACH | (10/23) | P | 2.51 | 0.443 | NO. 1 C. | 26 |
| 28 | CHECK AIM | (11/24) | | 4.81 | 0.143 | C.SECT. | 22 24 |
| 29 | PRIME | 25 | | 4.40 | 2.302 | NO. 1 C. | 27 28 |
| 30 | FIRE | 26 | | 5.59 | 2.661 | NO. 1 C. | 29 |
| 31 | RECOIL | -- | | 1.00 | 0.0 | -- | 30 |
| 32 | SWAB BORE | 27 | | 8.67 | 3.552 | NO. 1 C. | 31 |
| 33 | END | -- | | 0.0 | 0.0 | -- | 32 |

[a]Task numbers in this column refer to empirical data measurements in Appendix A.

Table 13. Input data for FDC crew.

| Task No. | Description | Data Task[a] | Task Type | Mean (sec) | SD (sec)[b] | Crewmember | Precursor Task(s) | |
|---|---|---|---|---|---|---|---|---|
| 1 | START | -- | | 0.0 | 0.0 | -- | -- | |
| 2 | CALL FOR FIRE | 1 | | 2.35 | (0.547) | -- | 1 | |
| 3 | RETURN CFF | 2 | | 2.12 | 0.915 | FDO | 2 | |
| 4 | ID REG'N POINT | 3 | | 3.16 | (1.080) | -- | 3 | |
| 5 | RETURN REG'N PT | 4 | | 2.26 | 1.202 | FDO | 4 | |
| 6 | AN: TARGT COORDS | 5 | | 6.21 | (1.509) | -- | 5 | |
| 7 | RETURN TGT CORDS | 6 | C | 7.22 | 2.343 | FDO | 6 | |
| 8 | DESCRIBES TARGET | 7 | | 4.06 | (2.058) | -- | 7 | |
| 9 | RETURN DESCRIPTN | 8 | | 2.03 | 1.085 | FDO | 8 | |
| 10 | ISSUE FIRE ORDER | 9 | C | 2.16 | 1.292 | FDO | 9 | |
| 11 | MESSAGE TO OBS'R | 10 | | 1.98 | 1.217 | FDO | 10 | |
| 12 | XMIT FIRE MIS'N | 11 | | 1.95 | 1.079 | COMPUTER | 2 | |
| 13 | XBAK FIRE MIS'N | 12 | | 1.33 | (0.476) | -- | 12 | |
| 14 | XMIT FIRE ORDER | 13 | | 1.52 | 0.548 | COMPUTER | 10 | 12 |
| 15 | XBAK FIRE ORDER | 14 | | 1.81 | (0.859) | -- | 13 | 14 |
| 16 | BEGIN PLOTTING | 15A | C | 16.14 | 3.051 | HCO | 4 | |
| 17 | FINSH PLOT & AN: | 15B | C | 23.00 | 4.348 | HCO | 7 | 16 |
| 18 | RETURN RANGE | 16 | | 2.28 | 0.963 | COMPUTER | 14 | 17 |
| 19 | AN: DEFLECTION | 17 | | 6.39 | 1.717 | HCO | 18 | |
| 20 | RETURN DEFL. | 18 | | 2.18 | 1.341 | COMPUTER | 19 | |
| 21 | REQUEST SITE | 19A | C | 10.16 | 6.627 | COMPUTER | 20 | |
| 22 | COMP & XMIT DEFL | 19B | C | 10.16 | 6.627 | COMPUTER | 25 | |
| 23 | RETURN DEFL | 20 | | 1.46 | (0.922) | -- | 15 | 22 |
| 24 | COMP & AN: SITE | 21A | C | 17.64 | 6.315 | FDO | 11 | 17 |
| 25 | REPLY WITH SITE | 21B | C | 1.00 | 0.359 | FDO | 21 | 24 |
| 26 | COMP & XMIT QUAD | 22 | | 8.76 | 5.806 | COMPUTER | 23 | |
| 27 | RETURN QUAD | 23 | | 1.17 | (0.460) | -- | 26 | |
| 28 | END | -- | | 0.0 | 0.0 | -- | 27 | |

[a]Task numbers in this column refer to empirical data measurements in Appendix A.

[b]Standard deviations indicated in parentheses ( ) were set to 0.0, making these fixed time tasks.

Table 14. Input data for tank crew.

| Task No. | Description | Data Task[a] | Task Type | Mean (sec) | SD (sec) | Crewmember | Precursor Task(s) | |
|---|---|---|---|---|---|---|---|---|
| 1 | START | -- | | 0.000 | 0.000 | -- | -- | |
| 2 | ACQUIRE TARGET | -- | | 0.100 | 0.050 | T.CMDR. | 1 | |
| 3 | ACQUIRE TARGET | -- | | 0.200 | 0.100 | GUNNER | -2 | 1 |
| 4 | REPORT TARGET | -- | | 1.000 | 0.400 | GUNNER | -2 | 3 |
| 5 | SCAN REPORT AREA | -- | | 1.500 | 1.000 | T.CMDR. | -2 | 4 |
| 6 | SEE TARGET | -- | | 0.100 | 0.050 | T.CMDR. | -2 | 5 |
| 7 | TRAVERSE TURRET | 1A | | 0.274 | 0.158 | T.CMDR. | 2 | 6 |
| 8 | ISSUE COMMAND | 1B | | 0.274 | 0.105 | T.CMDR. | 2 | 6 |
| 9 | ARM - "UP" | 2 | | 1.916 | 0.807 | LOADER | 8 | |
| 10 | SET COMP. | 3A | | 0.500 | 0.298 | GUNNER | 8 | |
| 11 | ACQUIRE TARGET | 3B | | 0.731 | 0.360 | GUNNER | 7 | 10 |
| 12 | SELECT ROUND | 4 | | 5.745 | 2.427 | LOADER | 9 | |
| 13 | TRACK TARGET | 5A | | 0.592 | 0.421 | GUNNER | 11 | |
| 14 | LASER RANGE | 5B | | 0.592 | 0.421 | GUNNER | 13 | |
| 15 | CHECK RANGE | 6 | | 1.142 | 0.343 | T.CMDR. | 14 | |
| 16 | RANGE OK? | -- | | 0.000 | 0.000 | T.CMDR. | 15 | |
| 17 | ORDER: RE-LASE | -- | | 3.000 | 1.000 | T.CMDR. | -16 | 15 |
| 18 | RE-LASE | -- | | 3.000 | 1.000 | GUNNER | -16 | 17 |
| 19 | ORDER: MOVE OUT | 7A | | 0.365 | 0.086 | T.CMDR. | 16 | 18 |
| 20 | ORDER: TAKE OVER | 7B | | 0.400 | 0.090 | T.CMDR. | 19 | |
| 21 | MOVE FORWARD | 8A | | 3.603 | 0.354 | DRIVER | 19 | |
| 22 | GUIDE DRIVER | 9A | | 2.023 | 0.619 | GUNNER | 20 | |
| 23 | ORDER: STOP | 9B | | 0.300 | 0.238 | GUNNER | 21 | 22 |
| 24 | STOP | 8B | | 1.000 | 0.186 | DRIVER | 23 | |
| 25 | COMMAND FIRE | 10 | | 2.127 | 0.721 | T.CMDR. | 24 | |
| 26 | FINAL LAY | 11 | | 1.288 | 0.584 | GUNNER | 25 | |
| 27 | PULL TRIGGER | 12 | | 1.034 | 0.382 | GUNNER | 26 | |
| 28 | RECOIL TIME | -- | | 0.100 | 0.000 | -- | 9 | 27 |
| 29 | TRACK FLIGHT | 14A | | 0.500 | 0.289 | T.CMDR. | 9 | 27 |
| 30 | TRACK FLIGHT | -- | | 0.500 | 0.289 | GUNNER | 9 | 27 |
| 31 | REPORT IMPACT | 14B | | 1.081 | 0.246 | T.CMDR. | -32 | 29 |
| 32 | REPORT IMPACT | -- | | 1.500 | 0.500 | GUNNER | -31 | 30 |
| 33 | RELOAD | 13A | P | 5.682 | 2.712 | LOADER | 12 | 28 |
| 34 | ARM - "UP" | 13B | | 0.500 | 0.200 | LOADER | 33 | |

[a]Task numbers in this column refer to empirical data measurements in Appendix A.

Table 14. Input data for tank crew (continued).

| Task No. | Description | Data Task[a] | Task Type | Mean (sec) | SD (sec) | Crewmember | Precursor Task(s) | |
|---|---|---|---|---|---|---|---|---|
| 35 | SELECT NEXT | 4 | | 5.745 | 2.427 | LOADER | 34 | |
| 36 | ORDER: RE-ENGAGE | 15 | | 0.480 | 0.109 | T.CMDR. | 31 | 32 |
| 37 | RE-LAY & LASE | 16 | | 0.968 | 0.205 | GUNNER | 36 | |
| 38 | CHECK RANGE | 17 | | 1.601 | 0.873 | T.CMDR. | 37 | |
| 39 | FINAL LAY | 18 | | 0.610 | 0.105 | GUNNER | 38 | |
| 40 | PULL TRIGGER | 19 | | 0.747 | 0.158 | GUNNER | 39 | |
| 41 | RECOIL TIME | -- | | 0.100 | 0.000 | -- | 19 | 34 |
| 42 | TRACK FLIGHT | 21A | | 0.500 | 0.289 | T.CMDR. | 19 | 34 |
| 43 | TRACK FLIGHT | -- | | 0.500 | 0.289 | GUNNER | 19 | 34 |
| 44 | REPORT IMPACT | 21B | | 0.912 | 0.242 | T.CMDR. | 42 | |
| 45 | RELOAD | 20 | P | 5.699 | 2.262 | LOADER | 35 | 41 |
| 46 | "CEASE FIRE" | 22 | | 0.401 | 0.071 | T.CMDR. | 44 | |
| 47 | "BACK UP" | 23 | | 0.453 | 0.060 | T.CMDR. | 46 | |
| 48 | START BACK | 24A | | 3.616 | 0.116 | DRIVER | 47 | |
| 49 | "STOP" | 24B | | 0.300 | 0.032 | T.CMDR. | 48 | |
| 50 | STOP | 24C | | 1.000 | 0.061 | DRIVER | 49 | |
| 51 | END | -- | | 0.000 | 0.000 | -- | 50 | |

[a]Task numbers in this column refer to empirical data measurements in Appendix A.

Table 15. Input data for ITV-TOW crew.

| Task No. | Description | Data Task[a] | Task Type | Mean (sec) | SD (sec) | Crewmember | Precursor Task(s) |
|---|---|---|---|---|---|---|---|
| 1 | START | -- | | 0.0 | 0.0 | -- | -- |
| 2 | ALERT/GIVE ORDER | 1 | | 5.32 | 0.029 | SQD.LDR. | 1 |
| 3 | ERECT LAUNCHER | 2 | | 6.36 | 0.594 | GUNNER | 2 |
| 4 | SLEW TURRET | 3 | | 11.29 | 1.845 | GUNNER | 3 |
| 5 | AN: SELECT & ARM | 4A | | 0.75 | 0.006 | SQD.LDR. | 4 |
| 6 | ARM 1ST MISSILE | 4B | | 1.76 | 0.009 | GUNNER | 5 |
| 7 | AN: "FIRE" | 5 | | 2.02 | 0.597 | SQD.LDR. | 6 |
| 8 | FIRE/TRACK MIS'L | 6 | P | 19.37 | 0.843 | GUNNER | 7 |
| 9 | GIVE 2ND ORDER | 7 | | 7.91 | 0.396 | SQD.LDR. | 8 |
| 10 | TRAVERSE TURRET | 8 | | 4.80 | 1.679 | GUNNER | 9 |
| 11 | AN: ARM MISSILE | 9A | | 0.44 | 0.067 | SQD.LDR. | 10 |
| 12 | ARM 2ND MISSILE | 9B | | 1.02 | 0.103 | GUNNER | 11 |
| 13 | AN: "FIRE" | 10 | | 1.80 | 0.763 | SQD.LDR. | 12 |
| 14 | FIRE/TRACK MIS'L | 11 | P | 18.13 | 0.961 | GUNNER | 13 |
| 15 | AN: CEASE/RELOAD | 12 | | 2.17 | 0.639 | SQD.LDR. | 14 |
| 16 | POSITION TURRET | 13A | | 13.20 | 2.239 | GUNNER | 15 |
| 17 | OPEN HATCH | 13B | | 3.05 | 1.076 | LOADER | 16 |
| 18 | UNLOAD LEFT TUBE | 14 | P | 3.22 | 0.957 | LOADER | 17 |
| 19 | LOAD LEFT TUBE | 15 | P | 7.61 | 1.791 | LOADER | 18 |
| 20 | UNLOAD RGHT TUBE | 16 | P | 2.06 | 0.381 | LOADER | 19 |
| 21 | LOAD RIGHT TUBE | 17 | P | 8.12 | 1.281 | LOADER | 20 |
| 22 | CLOSE HATCH/"UP" | 18 | | 3.24 | 0.981 | LOADER | 21 |
| 23 | REARRANGE RACK | 19 | P | 6.39 | 0.778 | LOADER | 22 |
| 24 | END | -- | | 0.0 | 0.0 | -- | 23 |

[a]Task numbers in this column refer to empirical data measurements in Appendix A.

# APPENDIX C
## TASK SCHEMATICS

Figures 6 though 9 are the schematic representations of the task lists in Appendix B.

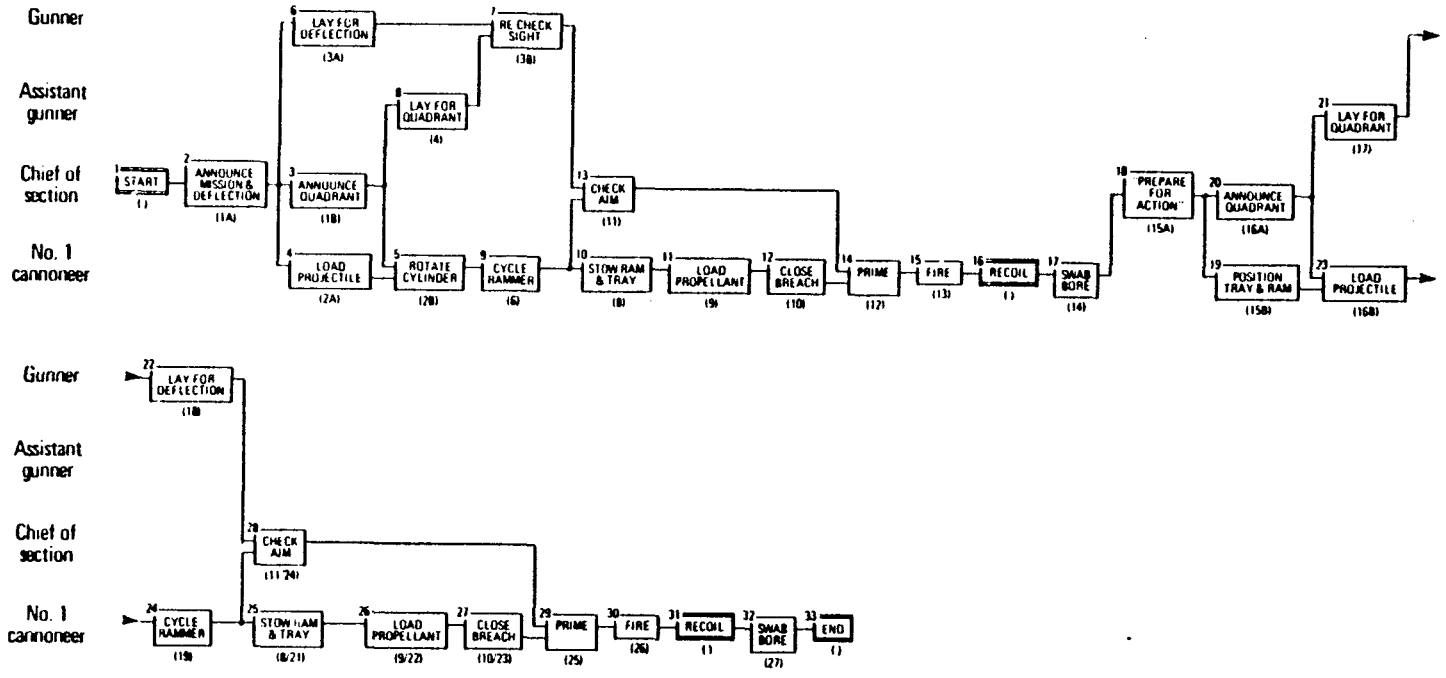



Figure 6. Task schematic for gun crew.

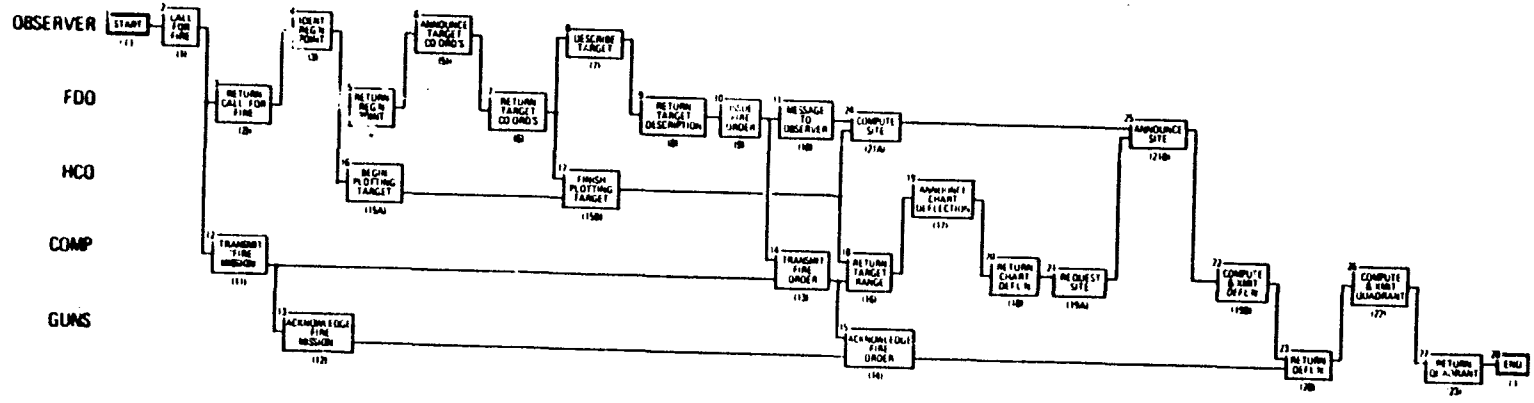



Figure 7. Task schematic for FDC crew.

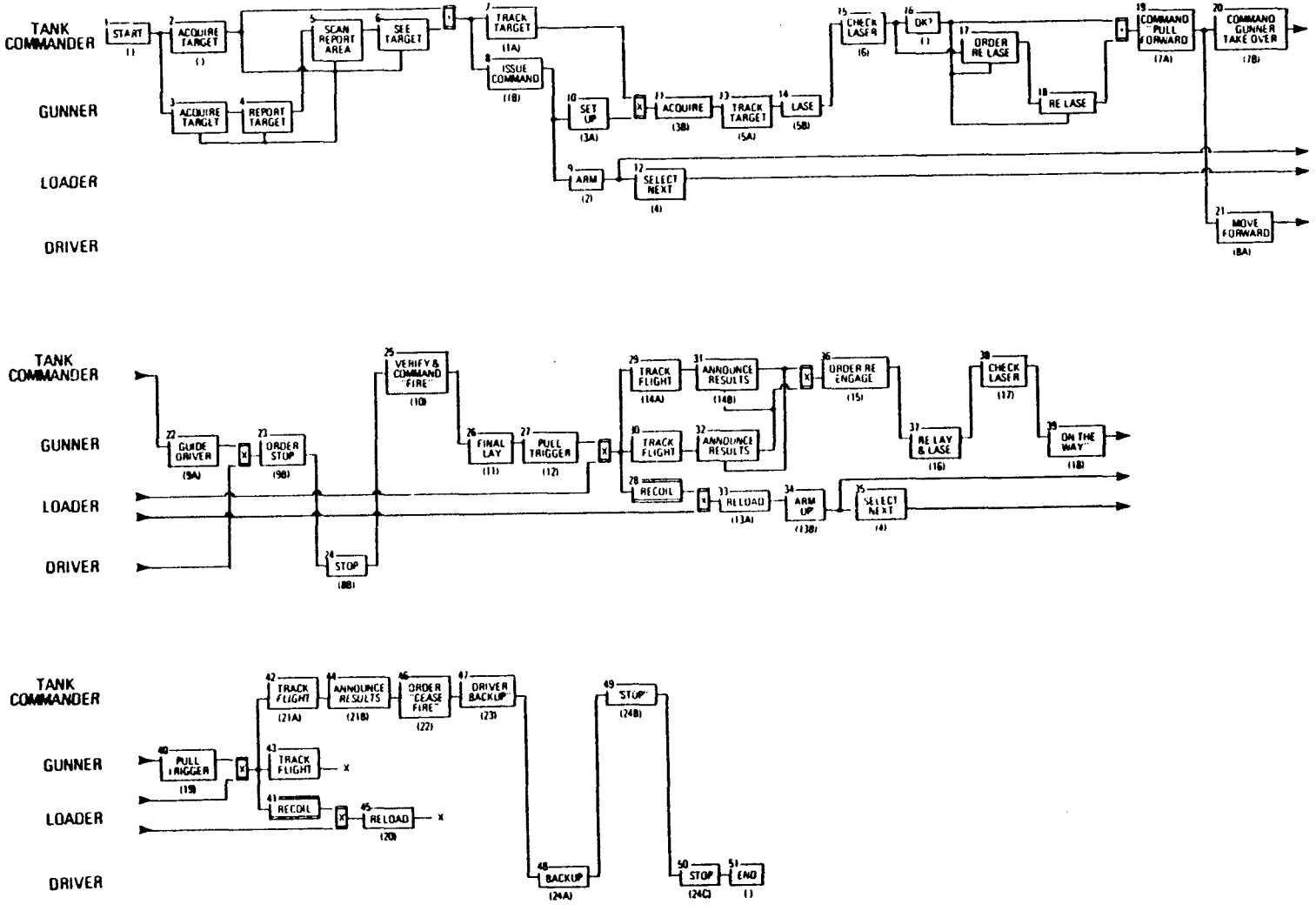



Figure 8. Task schematic for tank crew.

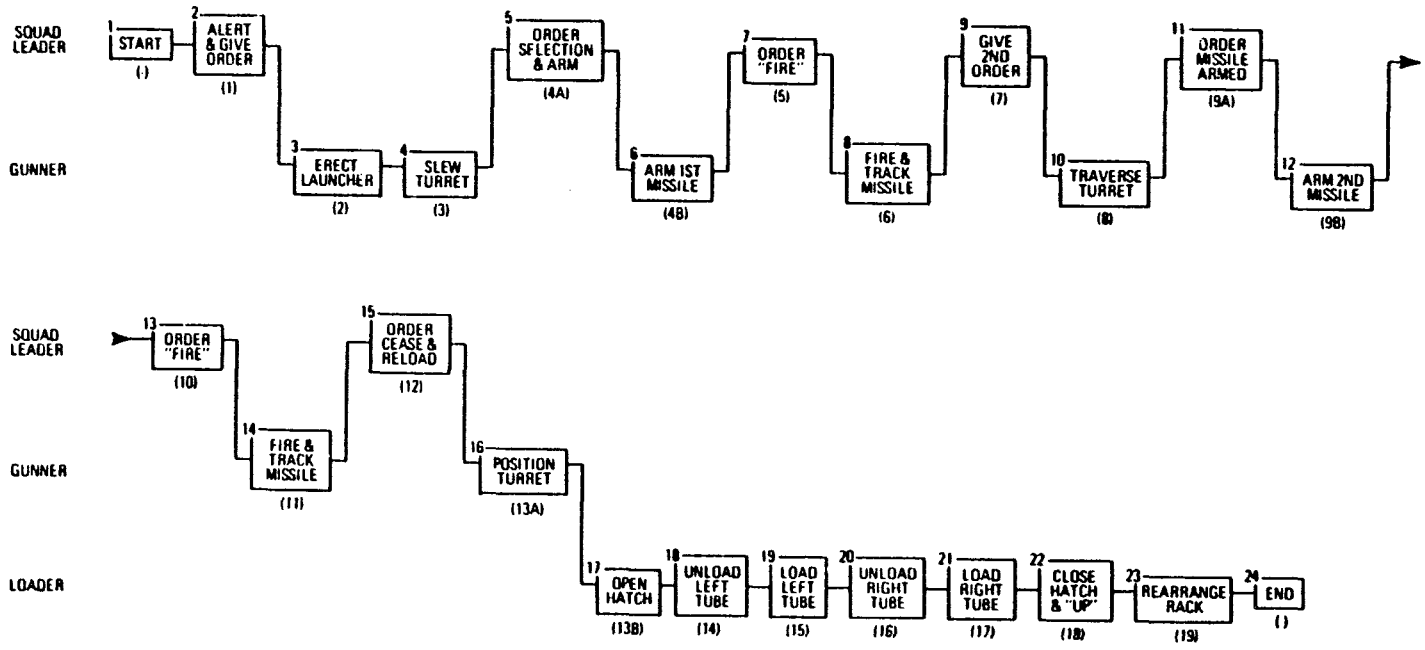



Figure 9. Task schematic for ITV-TOW crew.

## APPENDIX D
## BEST-FIT RESULTS

In this appendix (Tables 16 through 19), we present the Monte Carlo results from the CREW III code for the four crews by individual crewmember.* The fractional difference is the difference between these results and those predicted by Eq. (9).

*The individual crewmembers are referred to by the following abbreviations:

AG = Assistant gunner
C = Computer
CS = Chief of section
D = Driver
F = Fire direction officer
G = Gunner
H = Horizontal control operator
L = Loader
SL = Squad leader
TC = Tank commander

Table 16. Best-fit results for gun crew (undegraded mission time: 103.182 s).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| G | AG | CS | L | (s) | (s) | Performance | by Fit | Difference |
| 0.80 | 1.00 | 1.00 | 1.00 | 103.654 | 9.607 | 0.99545 | 0.98972 | -0.00575 |
| 1.00 | 0.80 | 1.00 | 1.00 | 105.171 | 9.475 | 0.98109 | 0.97477 | -0.00644 |
| 0.80 | 0.80 | 1.00 | 1.00 | 105.818 | 8.913 | 0.97509 | 0.96312 | -0.01227 |
| 0.50 | 1.00 | 1.00 | 1.00 | 106.426 | 10.119 | 0.96952 | 0.95136 | -0.01873 |
| 1.00 | 0.50 | 1.00 | 1.00 | 114.289 | 11.424 | 0.90282 | 0.90867 | 0.00648 |
| 0.80 | 0.50 | 1.00 | 1.00 | 112.799 | 11.392 | 0.91474 | 0.89854 | -0.01771 |
| 0.50 | 0.80 | 1.00 | 1.00 | 110.656 | 12.026 | 0.93246 | 0.92676 | -0.00611 |
| 0.50 | 0.50 | 1.00 | 1.00 | 116.808 | 12.745 | 0.88335 | 0.86681 | -0.01872 |
| 0.30 | 1.00 | 1.00 | 1.00 | 119.403 | 17.929 | 0.86415 | 0.88254 | 0.02128 |
| 1.00 | 0.30 | 1.00 | 1.00 | 131.091 | 17.151 | 0.78710 | 0.82385 | 0.04669 |
| 0.80 | 0.30 | 1.00 | 1.00 | 128.766 | 14.542 | 0.80131 | 0.81552 | 0.01773 |
| 0.20 | 0.80 | 1.00 | 1.00 | 136.763 | 29.263 | 0.75446 | 0.78392 | 0.03905 |
| 0.50 | 0.30 | 1.00 | 1.00 | 133.613 | 15.137 | 0.77225 | 0.78929 | 0.02207 |
| 0.30 | 0.50 | 1.00 | 1.00 | 125.489 | 17.824 | 0.82224 | 0.80931 | -0.01573 |
| 0.30 | 0.30 | 1.00 | 1.00 | 133.808 | 14.324 | 0.77112 | 0.74133 | -0.03863 |
| 0.80 | 1.00 | 0.80 | 1.00 | 109.192 | 9.229 | 0.94496 | 0.93222 | -0.01348 |
| 1.00 | 0.80 | 1.00 | 0.80 | 123.090 | 12.510 | 0.83826 | 0.84168 | 0.00407 |
| 0.80 | 0.80 | 0.80 | 0.80 | 129.511 | 11.256 | 0.79670 | 0.79187 | -0.00607 |
| 0.50 | 1.00 | 0.50 | 1.00 | 133.467 | 11.907 | 0.77309 | 0.76884 | -0.00550 |
| 1.00 | 0.50 | 1.00 | 0.50 | 183.749 | 17.943 | 0.56154 | 0.56138 | -0.00028 |
| 0.80 | 0.50 | 0.80 | 0.50 | 188.181 | 15.897 | 0.54831 | 0.53878 | -0.01739 |
| 0.50 | 0.80 | 0.50 | 0.80 | 150.590 | 13.356 | 0.68519 | 0.67078 | -0.02102 |
| 0.50 | 0.50 | 0.50 | 0.50 | 206.819 | 19.175 | 0.49890 | 0.47984 | -0.03820 |
| 0.30 | 1.00 | 0.30 | 1.00 | 179.919 | 16.619 | 0.57349 | 0.58273 | 0.01610 |
| 1.00 | 0.30 | 1.00 | 0.30 | 292.827 | 31.478 | 0.35237 | 0.34482 | -0.02141 |
| 0.80 | 0.30 | 0.80 | 0.30 | 297.240 | 33.308 | 0.34713 | 0.33616 | -0.03162 |
| 0.20 | 0.80 | 0.30 | 0.80 | 208.957 | 23.501 | 0.49380 | 0.49484 | 0.00212 |
| 0.50 | 0.30 | 0.50 | 0.30 | 311.130 | 31.322 | 0.33164 | 0.31223 | -0.05851 |
| 0.30 | 0.50 | 0.30 | 0.50 | 242.088 | 18.255 | 0.42622 | 0.40009 | -0.06129 |
| 0.30 | 0.30 | 0.30 | 0.30 | 349.141 | 33.313 | 0.29553 | 0.27638 | -0.06479 |
| 1.00 | 1.00 | 0.80 | 1.00 | 109.788 | 9.748 | 0.93983 | 0.94313 | 0.00351 |
| 1.00 | 1.00 | 1.00 | 0.80 | 122.170 | 12.503 | 0.84458 | 0.86192 | 0.02053 |
| 1.00 | 1.00 | 0.80 | 0.80 | 126.276 | 12.861 | 0.81711 | 0.81798 | 0.00105 |
| 1.00 | 1.00 | 0.50 | 1.00 | 128.549 | 9.952 | 0.80267 | 0.80159 | -0.00134 |
| 1.00 | 1.00 | 1.00 | 0.50 | 181.440 | 19.213 | 0.56868 | 0.59566 | 0.04744 |
| 1.00 | 1.00 | 0.80 | 0.50 | 183.383 | 19.604 | 0.56266 | 0.57434 | 0.02077 |
| 1.00 | 1.00 | 0.50 | 0.80 | 145.418 | 12.698 | 0.70955 | 0.70935 | -0.00029 |
| 1.00 | 1.00 | 0.50 | 0.50 | 201.946 | 18.327 | 0.51094 | 0.51858 | 0.01496 |
| 1.00 | 1.00 | 0.30 | 1.00 | 168.178 | 9.884 | 0.61353 | 0.63253 | 0.03097 |

Table 16. Best-fit results for gun crew (undegraded mission time: 103k.182 s) (continued).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| G | AG | CS | L | (s) | (s) | Performance | by Fit | Difference |
| 1.00 | 1.00 | 1.00 | 0.30 | 281.705 | 28.332 | 0.36628 | 0.37254 | 0.01711 |
| 1.00 | 1.00 | 0.80 | 0.30 | 301.321 | 32.496 | 0.34243 | 0.36409 | 0.06325 |
| 1.00 | 1.00 | 0.30 | 0.80 | 183.812 | 11.908 | 0.56135 | 0.57366 | 0.02195 |
| 1.00 | 1.00 | 0.50 | 0.30 | 306.564 | 32.007 | 0.33658 | 0.34086 | 0.01272 |
| 1.00 | 1.00 | 0.30 | 0.50 | 230.123 | 20.680 | 0.44838 | 0.44213 | -0.01393 |
| 1.00 | 1.00 | 0.30 | 0.30 | 333.926 | 30.359 | 0.30900 | 0.30607 | -0.00947 |

Table 17. Best-fit results for FDC crew. (undegraded mission time: 93.375 s).

| Crewmember Performance | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|
| F | C | H | (s) | (s) | Performance | by Fit | Difference |
| 0.80 | 1.00 | 1.00 | 98.055 | 13.402 | 0.95227 | 0.95680 | 0.00476 |
| 0.50 | 1.00 | 1.00 | 116.395 | 15.013 | 0.80223 | 0.83152 | 0.03651 |
| 0.30 | 1.00 | 1.00 | 156.814 | 24.770 | 0.59545 | 0.63306 | 0.06316 |
| 1.00 | 0.80 | 1.00 | 100.629 | 13.182 | 0.92791 | 0.91571 | -0.01315 |
| 0.80 | 0.80 | 1.00 | 102.055 | 14.023 | 0.91495 | 0.88168 | -0.03636 |
| 0.50 | 0.80 | 1.00 | 123.434 | 18.138 | 0.75648 | 0.77419 | 0.02342 |
| 0.30 | 0.80 | 1.00 | 165.834 | 25.010 | 0.56306 | 0.59928 | 0.06431 |
| 1.00 | 0.50 | 1.00 | 124.391 | 25.575 | 0.75056 | 0.74533 | -0.00710 |
| 0.80 | 0.50 | 1.00 | 125.777 | 22.691 | 0.74239 | 0.72263 | -0.02661 |
| 0.50 | 0.50 | 1.00 | 141.272 | 25.788 | 0.66096 | 0.64880 | -0.01840 |
| 0.30 | 0.50 | 1.00 | 180.216 | 33.306 | 0.51813 | 0.52129 | 0.00610 |
| 1.00 | 0.30 | 1.00 | 167.693 | 31.789 | 0.55682 | 0.57271 | 0.02853 |
| 0.80 | 0.30 | 1.00 | 171.653 | 31.460 | 0.54398 | 0.55921 | 0.02801 |
| 0.50 | 0.30 | 1.00 | 184.069 | 36.961 | 0.50728 | 0.51395 | 0.01315 |
| 0.30 | 0.30 | 1.00 | 213.197 | 38.895 | 0.43798 | 0.43053 | -0.01700 |
| 1.00 | 1.00 | 0.80 | 102.417 | 11.930 | 0.91171 | 0.89700 | -0.01614 |
| 0.80 | 1.00 | 0.80 | 107.952 | 12.956 | 0.86497 | 0.86433 | -0.00074 |
| 0.50 | 1.00 | 0.80 | 123.335 | 17.658 | 0.75708 | 0.76078 | 0.00488 |
| 0.30 | 1.00 | 0.80 | 162.743 | 24.930 | 0.57376 | 0.59121 | 0.03041 |
| 1.00 | 0.80 | 0.80 | 115.333 | 17.410 | 0.80961 | 0.83065 | 0.02599 |
| 0.80 | 0.80 | 0.80 | 117.738 | 16.379 | 0.79307 | 0.80256 | 0.01196 |
| 0.50 | 0.80 | 0.80 | 131.961 | 16.900 | 0.70760 | 0.71251 | 0.00695 |
| 0.30 | 0.80 | 0.80 | 168.845 | 25.147 | 0.55302 | 0.56164 | 0.01558 |
| 1.00 | 0.50 | 0.80 | 137.610 | 21.255 | 0.67855 | 0.68799 | 0.01391 |
| 0.80 | 0.50 | 0.80 | 136.008 | 18.057 | 0.68654 | 0.66860 | -0.02613 |
| 0.50 | 0.50 | 0.80 | 144.619 | 22.038 | 0.64566 | 0.60491 | -0.06311 |
| 0.30 | 0.50 | 0.80 | 186.496 | 30.659 | 0.50068 | 0.49258 | -0.01619 |
| 1.00 | 0.30 | 0.80 | 176.535 | 32.935 | 0.52893 | 0.53824 | 0.01760 |
| 0.80 | 0.30 | 0.80 | 184.951 | 36.285 | 0.50486 | 0.52630 | 0.04246 |
| 0.50 | 0.30 | 0.80 | 189.537 | 36.164 | 0.49265 | 0.48602 | -0.01345 |
| 0.30 | 0.30 | 0.80 | 221.583 | 42.459 | 0.42140 | 0.41076 | -0.02526 |
| 1.00 | 1.00 | 0.50 | 133.984 | 15.341 | 0.69691 | 0.69054 | -0.00914 |
| 0.80 | 1.00 | 0.50 | 138.912 | 14.346 | 0.67219 | 0.67102 | -0.00174 |
| 0.50 | 1.00 | 0.50 | 150.724 | 15.297 | 0.61951 | 0.60689 | -0.02038 |
| 0.30 | 1.00 | 0.50 | 184.610 | 25.399 | 0.50580 | 0.49388 | -0.02355 |
| 1.00 | 0.80 | 0.50 | 145.915 | 16.508 | 0.63993 | 0.65054 | 0.01659 |
| 0.80 | 0.80 | 0.50 | 145.589 | 18.634 | 0.64136 | 0.63318 | -0.01275 |
| 0.50 | 0.80 | 0.50 | 156.978 | 20.520 | 0.59483 | 0.57577 | -0.03204 |
| 0.30 | 0.80 | 0.50 | 189.092 | 24.921 | 0.49381 | 0.47308 | -0.04198 |

Table 17. Best-fit results for FDC crew (undegraded mission time: (93.375 s) (continued).

| Crewmember Performance F | C | H | Mean (s) | SD (s) | Crew Performance | Predicted by Fit | Fractional Difference |
|---|---|---|---|---|---|---|---|
| 1.00 | 0.50 | 0.50 | 171.036 | 23.184 | 0.54594 | 0.55965 | 0.02512 |
| 0.80 | 0.50 | 0.50 | 167.775 | 21.257 | 0.55655 | 0.54676 | -0.01759 |
| 0.50 | 0.50 | 0.50 | 177.242 | 24.738 | 0.52682 | 0.50341 | -0.04443 |
| 0.30 | 0.50 | 0.50 | 202.601 | 27.660 | 0.46088 | 0.42311 | -0.08195 |
| 1.00 | 0.30 | 0.50 | 212.758 | 41.553 | 0.43888 | 0.45637 | 0.03985 |
| 0.80 | 0.30 | 0.50 | 209.611 | 33.765 | 0.44547 | 0.44776 | 0.00514 |
| 0.50 | 0.30 | 0.50 | 220.650 | 37.541 | 0.42318 | 0.41826 | -0.01162 |
| 0.30 | 0.30 | 0.50 | 237.129 | 40.228 | 0.39377 | 0.36129 | -0.08249 |
| 1.00 | 1.00 | 0.30 | 199.124 | 21.458 | 0.46893 | 0.49128 | 0.04767 |
| 0.80 | 1.00 | 0.30 | 202.856 | 22.735 | 0.46030 | 0.48132 | 0.04566 |
| 0.50 | 1.00 | 0.30 | 208.158 | 23.009 | 0.44858 | 0.44741 | -0.00261 |
| 0.30 | 1.00 | 0.30 | 225.230 | 26.479 | 0.41458 | 0.38283 | -0.07657 |
| 1.00 | 0.80 | 0.30 | 205.803 | 22.368 | 0.45371 | 0.47069 | 0.03743 |
| 0.80 | 0.80 | 0.30 | 207.053 | 21.473 | 0.45097 | 0.46154 | 0.02343 |
| 0.50 | 0.80 | 0.30 | 214.312 | 27.083 | 0.43570 | 0.43027 | -0.01246 |
| 0.30 | 0.80 | 0.30 | 239.124 | 29.276 | 0.39049 | 0.37021 | -0.05192 |
| 1.00 | 0.50 | 0.30 | 227.842 | 27.096 | 0.40982 | 0.42120 | 0.02776 |
| 0.80 | 0.50 | 0.30 | 231.984 | 31.477 | 0.40251 | 0.41385 | 0.02819 |
| 0.50 | 0.50 | 0.30 | 238.886 | 27.625 | 0.39088 | 0.38853 | -0.00600 |
| 0.30 | 0.50 | 0.30 | 254.987 | 36.194 | 0.36620 | 0.33889 | -0.07456 |
| 1.00 | 0.30 | 0.30 | 270.894 | 34.346 | 0.34469 | 0.35990 | 0.04412 |
| 0.80 | 0.30 | 0.30 | 281.183 | 44.969 | 0.33208 | 0.35452 | 0.06758 |
| 0.50 | 0.30 | 0.30 | 279.526 | 45.571 | 0.33405 | 0.33578 | 0.00517 |
| 0.30 | 0.30 | 0.30 | 290.646 | 39.646 | 0.32127 | 0.29805 | -0.07228 |

Table 18. Best-fit results for tank crew (undegraded mission time: 28.062 s).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| TC | G | L | D | (s) | (s) | Performance | by Fit | Difference |
| 0.80 | 1.00 | 1.00 | 1.00 | 29.269 | 3.447 | 0.95876 | 0.97058 | 0.01232 |
| 1.00 | 0.80 | 1.00 | 1.00 | 28.129 | 3.209 | 0.99762 | 0.97807 | -0.01960 |
| 0.80 | 0.80 | 1.00 | 1.00 | 30.154 | 2.902 | 0.93062 | 0.92338 | -0.00778 |
| 0.50 | 1.00 | 1.00 | 1.00 | 33.957 | 3.489 | 0.82640 | 0.82517 | -0.00149 |
| 1.00 | 0.50 | 1.00 | 1.00 | 33.567 | 3.986 | 0.83600 | 0.84226 | 0.00749 |
| 0.80 | 0.50 | 1.00 | 1.00 | 35.255 | 3.659 | 0.79597 | 0.80139 | 0.00680 |
| 0.50 | 0.80 | 1.00 | 1.00 | 35.574 | 3.889 | 0.78883 | 0.79080 | 0.00250 |
| 0.50 | 0.50 | 1.00 | 1.00 | 40.308 | 4.510 | 0.69619 | 0.69960 | 0.00489 |
| 0.30 | 1.00 | 1.00 | 1.00 | 42.989 | 4.989 | 0.65277 | 0.65170 | -0.00164 |
| 1.00 | 0.30 | 1.00 | 1.00 | 41.624 | 6.690 | 0.67418 | 0.66757 | -0.00981 |
| 0.80 | 0.30 | 1.00 | 1.00 | 44.522 | 6.196 | 0.63030 | 0.64163 | 0.01799 |
| 0.20 | 0.80 | 1.00 | 1.00 | 56.800 | 6.425 | 0.49405 | 0.50250 | 0.01710 |
| 0.50 | 0.30 | 1.00 | 1.00 | 49.791 | 6.321 | 0.56360 | 0.57468 | 0.01967 |
| 0.30 | 0.50 | 1.00 | 1.00 | 50.158 | 5.374 | 0.55947 | 0.57079 | 0.02023 |
| 0.30 | 0.30 | 1.00 | 1.00 | 59.920 | 7.150 | 0.46832 | 0.48481 | 0.03521 |
| 0.80 | 1.00 | 0.80 | 1.00 | 31.113 | 5.100 | 0.90194 | 0.90350 | 0.00173 |
| 1.00 | 0.80 | 1.00 | 0.80 | 30.269 | 2.751 | 0.92709 | 0.90876 | -0.01977 |
| 0.80 | 0.80 | 0.80 | 0.80 | 34.007 | 4.068 | 0.82518 | 0.80812 | -0.02068 |
| 0.50 | 1.00 | 0.50 | 1.00 | 43.562 | 10.171 | 0.64419 | 0.64829 | 0.00637 |
| 1.00 | 0.50 | 1.00 | 0.50 | 41.343 | 4.524 | 0.67876 | 0.66685 | -0.01754 |
| 0.80 | 0.50 | 0.80 | 0.50 | 44.862 | 6.059 | 0.62552 | 0.61101 | -0.02319 |
| 0.50 | 0.80 | 0.50 | 0.80 | 44.430 | 8.751 | 0.63160 | 0.59767 | -0.05372 |
| 0.50 | 0.50 | 0.50 | 0.50 | 53.471 | 8.504 | 0.52481 | 0.48255 | -0.08053 |
| 0.30 | 1.00 | 0.30 | 1.00 | 64.747 | 15.327 | 0.43341 | 0.41940 | -0.03232 |
| 1.00 | 0.30 | 1.00 | 0.30 | 60.571 | 6.247 | 0.46329 | 0.44888 | -0.03112 |
| 0.80 | 0.30 | 0.80 | 0.30 | 64.655 | 7.502 | 0.43403 | 0.42286 | -0.02572 |
| 0.20 | 0.80 | 0.30 | 0.80 | 75.645 | 16.959 | 0.37097 | 0.34271 | -0.07619 |
| 0.50 | 0.30 | 0.50 | 0.30 | 73.515 | 8.361 | 0.38172 | 0.35707 | -0.06456 |
| 0.30 | 0.50 | 0.30 | 0.50 | 74.043 | 12.731 | 0.37900 | 0.34315 | -0.09458 |
| 0.30 | 0.30 | 0.30 | 0.30 | 92.668 | 14.796 | 0.30282 | 0.27455 | -0.09338 |
| 1.00 | 1.00 | 0.80 | 1.00 | 29.669 | 3.953 | 0.94584 | 0.95579 | 0.01052 |
| 1.00 | 1.00 | 1.00 | 0.80 | 29.127 | 2.757 | 0.96344 | 0.95443 | -0.00935 |
| 1.00 | 1.00 | 0.80 | 0.80 | 31.219 | 4.046 | 0.89888 | 0.88949 | -0.01044 |
| 1.00 | 1.00 | 0.50 | 1.00 | 37.789 | 8.959 | 0.74260 | 0.76899 | 0.03554 |
| 1.00 | 1.00 | 1.00 | 0.50 | 36.257 | 5.445 | 0.77397 | 0.77999 | 0.00778 |
| 1.00 | 1.00 | 0.80 | 0.50 | 38.315 | 4.906 | 0.73240 | 0.73608 | 0.00501 |
| 1.00 | 1.00 | 0.50 | 0.80 | 39.167 | 10.617 | 0.71647 | 0.72548 | 0.01258 |
| 1.00 | 1.00 | 0.50 | 0.50 | 44.562 | 7.492 | 0.62973 | 0.62008 | -0.01533 |
| 1.00 | 1.00 | 0.30 | 1.00 | 53.948 | 16.740 | 0.52017 | 0.54955 | 0.05649 |
| 1.00 | 1.00 | 1.00 | 0.30 | 48.399 | 4.738 | 0.57981 | 0.58838 | 0.01479 |
| 1.00 | 1.00 | 0.80 | 0.30 | 50.247 | 5.262 | 0.55848 | 0.56304 | 0.00816 |

Table 18. Best-fit results for tank crew (undegraded mission time: 28.062 s) (continued).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| TC | G | L | D | (s) | (s) | Performance | by Fit | Difference |
| 1.00 | 1.00 | 0.30 | 0.80 | 52.559 | 12.942 | 0.53391 | 0.52697 | -0.01301 |
| 1.00 | 1.00 | 0.50 | 0.30 | 55.807 | 8.206 | 0.50284 | 0.49256 | -0.02045 |
| 1.00 | 1.00 | 0.30 | 0.50 | 60.075 | 16.473 | 0.46712 | 0.46905 | 0.00414 |
| 1.00 | 1.00 | 0.30 | 0.30 | 68.389 | 15.890 | 0.41033 | 0.39224 | -0.04409 |
| 0.90 | 1.00 | 1.00 | 1.00 | 27.814 | 3.002 | 1.00892 | 1.00000 | -0.00884 |
| 0.80 | 1.00 | 1.00 | 1.00 | 28.817 | 3.499 | 0.97380 | 0.97058 | -0.00331 |
| 0.70 | 1.00 | 1.00 | 1.00 | 30.011 | 3.638 | 0.93506 | 0.93148 | -0.00382 |
| 0.60 | 1.00 | 1.00 | 1.00 | 32.005 | 5.784 | 0.87680 | 0.88402 | 0.00823 |
| 0.50 | 1.00 | 1.00 | 1.00 | 34.209 | 3.629 | 0.82031 | 0.82517 | 0.00592 |
| 0.40 | 1.00 | 1.00 | 1.00 | 37.263 | 3.822 | 0.75308 | 0.75026 | -0.00374 |
| 0.30 | 1.00 | 1.00 | 1.00 | 42.925 | 4.607 | 0.65374 | 0.65170 | -0.00312 |
| 0.20 | 1.00 | 1.00 | 1.00 | 54.915 | 6.985 | 0.51101 | 0.51615 | 0.01007 |
| 0.10 | 1.00 | 1.00 | 1.00 | 91.753 | 14.124 | 0.30584 | 0.31793 | 0.03952 |
| 1.00 | 0.90 | 1.00 | 1.00 | 27.957 | 3.207 | 1.00376 | 1.00000 | -0.00374 |
| 1.00 | 0.80 | 1.00 | 1.00 | 28.319 | 2.977 | 0.99092 | 0.97807 | -0.01297 |
| 1.00 | 0.70 | 1.00 | 1.00 | 29.723 | 3.112 | 0.94412 | 0.94266 | -0.00154 |
| 1.00 | 0.60 | 1.00 | 1.00 | 31.247 | 3.455 | 0.89807 | 0.89855 | 0.00054 |
| 1.00 | 0.50 | 1.00 | 1.00 | 33.858 | 4.465 | 0.82881 | 0.84226 | 0.01622 |
| 1.00 | 0.40 | 1.00 | 1.00 | 36.448 | 4.839 | 0.76992 | 0.76830 | -0.00211 |
| 1.00 | 0.30 | 1.00 | 1.00 | 43.332 | 7.335 | 0.64760 | 0.66757 | 0.03083 |
| 1.00 | 0.20 | 1.00 | 1.00 | 52.941 | 8.038 | 0.53006 | 0.52424 | -0.01098 |
| 1.00 | 0.10 | 1.00 | 1.00 | 91.170 | 14.283 | 0.30780 | 0.31029 | 0.00809 |
| 1.00 | 1.00 | 0.90 | 1.00 | 28.505 | 4.193 | 0.98446 | 0.99684 | 0.01258 |
| 1.00 | 1.00 | 0.80 | 1.00 | 28.947 | 4.132 | 0.96943 | 0.95579 | -0.01407 |
| 1.00 | 1.00 | 0.70 | 1.00 | 30.769 | 4.567 | 0.91202 | 0.90607 | -0.00652 |
| 1.00 | 1.00 | 0.60 | 1.00 | 33.068 | 6.157 | 0.84862 | 0.84504 | -0.00421 |
| 1.00 | 1.00 | 0.50 | 1.00 | 35.749 | 8.215 | 0.78497 | 0.76899 | -0.02036 |
| 1.00 | 1.00 | 0.40 | 1.00 | 41.624 | 9.507 | 0.67418 | 0.67278 | -0.00207 |
| 1.00 | 1.00 | 0.30 | 1.00 | 55.140 | 16.834 | 0.50892 | 0.54955 | 0.07983 |
| 1.00 | 1.00 | 0.20 | 1.00 | 76.463 | 22.704 | 0.36700 | 0.39120 | 0.06595 |
| 1.00 | 1.00 | 0.10 | 1.00 | 132.740 | 44.313 | 0.21141 | 0.19391 | -0.08274 |
| 1.00 | 1.00 | 1.00 | 0.90 | 28.310 | 3.580 | 0.99124 | 0.99561 | 0.00441 |
| 1.00 | 1.00 | 1.00 | 0.80 | 29.879 | 3.262 | 0.93919 | 0.95443 | 0.01623 |
| 1.00 | 1.00 | 1.00 | 0.70 | 31.282 | 3.160 | 0.89707 | 0.90622 | 0.01020 |
| 1.00 | 1.00 | 1.00 | 0.60 | 33.192 | 3.494 | 0.84544 | 0.84900 | 0.00420 |
| 1.00 | 1.00 | 1.00 | 0.50 | 36.114 | 3.504 | 0.77704 | 0.77999 | 0.00380 |
| 1.00 | 1.00 | 1.00 | 0.40 | 41.305 | 4.185 | 0.67939 | 0.69516 | 0.02322 |
| 1.00 | 1.00 | 1.00 | 0.30 | 49.094 | 4.714 | 0.57160 | 0.58838 | 0.02936 |
| 1.00 | 1.00 | 1.00 | 0.20 | 64.482 | 7.109 | 0.43519 | 0.44993 | 0.03387 |
| 1.00 | 1.00 | 1.00 | 0.10 | 109.445 | 11.716 | 0.25640 | 0.26346 | 0.02753 |

Table 19. Best-fit results for ITV-TOW Crew (undegraded mission time: 157.824 s).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| SL | G | D[a] | L | (s) | (s) | Performance | by Fit | Difference |
| 0.80 | 1.00 | 1.00 | 1.00 | 162.926 | 4.935 | 0.96869 | 0.96960 | 0.00094 |
| 0.50 | 1.00 | 1.00 | 1.00 | 177.587 | 5.522 | 0.88871 | 0.88690 | -0.00204 |
| 0.30 | 1.00 | 1.00 | 1.00 | 205.723 | 5.816 | 0.76717 | 0.76817 | 0.00131 |
| 1.00 | 0.80 | 1.00 | 1.00 | 176.789 | 5.384 | 0.89273 | 0.89306 | 0.00037 |
| 0.80 | 0.80 | 1.00 | 1.00 | 180.935 | 5.678 | 0.87227 | 0.86854 | -0.00428 |
| 0.50 | 0.80 | 1.00 | 1.00 | 196.637 | 5.682 | 0.80262 | 0.80159 | -0.00128 |
| 0.30 | 0.80 | 1.00 | 1.00 | 223.738 | 7.682 | 0.70540 | 0.70334 | -0.00292 |
| 1.00 | 0.50 | 1.00 | 1.00 | 234.026 | 8.866 | 0.67439 | 0.67497 | 0.00086 |
| 0.80 | 0.50 | 1.00 | 1.00 | 239.131 | 8.594 | 0.65999 | 0.66087 | 0.00133 |
| 0.50 | 0.50 | 1.00 | 1.00 | 254.489 | 9.256 | 0.62016 | 0.62138 | 0.00197 |
| 0.30 | 0.50 | 1.00 | 1.00 | 281.568 | 10.536 | 0.56052 | 0.56067 | 0.00026 |
| 1.00 | 0.30 | 1.00 | 1.00 | 337.737 | 14.396 | 0.46730 | 0.46968 | 0.00509 |
| 0.80 | 0.30 | 1.00 | 1.00 | 341.848 | 14.035 | 0.46168 | 0.46281 | 0.00245 |
| 0.50 | 0.30 | 1.00 | 1.00 | 353.790 | 15.868 | 0.44610 | 0.44309 | -0.00674 |
| 0.30 | 0.30 | 1.00 | 1.00 | 384.025 | 15.719 | 0.41097 | 0.41133 | 0.00086 |
| 1.00 | 1.00 | 1.00 | 0.80 | 166.522 | 5.424 | 0.94777 | 0.94837 | 0.00064 |
| 0.80 | 1.00 | 1.00 | 0.80 | 171.849 | 5.230 | 0.91839 | 0.92077 | 0.00260 |
| 0.50 | 1.00 | 1.00 | 0.80 | 186.606 | 6.219 | 0.84576 | 0.84588 | 0.00014 |
| 0.30 | 1.00 | 1.00 | 0.80 | 213.642 | 6.392 | 0.73873 | 0.73720 | -0.00207 |
| 1.00 | 0.80 | 1.00 | 0.80 | 184.608 | 6.093 | 0.85491 | 0.85147 | -0.00403 |
| 0.80 | 0.80 | 1.00 | 0.80 | 190.765 | 5.519 | 0.82732 | 0.82915 | 0.00221 |
| 0.50 | 0.80 | 1.00 | 0.80 | 205.345 | 6.459 | 0.76858 | 0.76792 | -0.00085 |
| 0.30 | 0.80 | 1.00 | 0.80 | 234.372 | 6.348 | 0.67339 | 0.67728 | 0.00578 |
| 1.00 | 0.50 | 1.00 | 0.80 | 242.031 | 9.018 | 0.65208 | 0.65094 | -0.00175 |
| 0.80 | 0.50 | 1.00 | 0.80 | 248.679 | 8.452 | 0.63465 | 0.63782 | 0.00499 |
| 0.50 | 0.50 | 1.00 | 0.80 | 264.326 | 9.542 | 0.59708 | 0.60096 | 0.00649 |
| 0.30 | 0.50 | 1.00 | 0.80 | 290.175 | 8.912 | 0.54389 | 0.54398 | 0.00017 |
| 1.00 | 0.30 | 1.00 | 0.80 | 345.089 | 14.501 | 0.45734 | 0.45792 | 0.00125 |
| 0.80 | 0.30 | 1.00 | 0.80 | 349.241 | 15.161 | 0.45191 | 0.45138 | -0.00116 |
| 0.50 | 0.30 | 1.00 | 0.80 | 366.428 | 16.578 | 0.43071 | 0.43261 | 0.00440 |
| 0.30 | 0.30 | 1.00 | 0.80 | 392.880 | 15.756 | 0.40171 | 0.40228 | 0.00141 |
| 1.00 | 1.00 | 1.00 | 0.50 | 192.296 | 7.700 | 0.82073 | 0.82218 | 0.00177 |
| 0.80 | 1.00 | 1.00 | 0.50 | 196.299 | 6.867 | 0.80400 | 0.80136 | -0.00328 |
| 0.50 | 1.00 | 1.00 | 0.50 | 212.653 | 7.363 | 0.74217 | 0.74402 | 0.00250 |

[a]No variation in driver performance.

Table 19. Best-fit results for ITV-TOW crew (undegraded mission time: 157.824 s) (continued).

| Crewmember Performance | | | | Mean | SD | Crew | Predicted | Fractional |
|---|---|---|---|---|---|---|---|---|
| SL | G | D[a] | L | (s) | (s) | Performance | by Fit | Difference |
| 0.30 | 1.00 | 1.00 | 0.50 | 239.250 | 7.978 | 0.65966 | 0.65862 | -0.00157 |
| 1.00 | 0.80 | 1.00 | 0.50 | 210.520 | 7.340 | 0.74969 | 0.74835 | -0.00179 |
| 0.80 | 0.80 | 1.00 | 0.50 | 215.862 | 8.208 | 0.73113 | 0.73105 | -0.00011 |
| 0.50 | 0.80 | 1.00 | 0.50 | 231.317 | 8.797 | 0.68228 | 0.68304 | 0.00110 |
| 0.30 | 0.80 | 1.00 | 0.50 | 258.199 | 9.577 | 0.61125 | 0.61038 | -0.00142 |
| 1.00 | 0.50 | 1.00 | 0.50 | 267.275 | 9.079 | 0.59049 | 0.58890 | -0.00270 |
| 0.80 | 0.50 | 1.00 | 0.50 | 273.892 | 9.744 | 0.57623 | 0.57814 | 0.00332 |
| 0.50 | 0.50 | 1.00 | 0.50 | 288.085 | 10.372 | 0.54784 | 0.54769 | -0.00027 |
| 0.30 | 0.50 | 1.00 | 0.50 | 314.944 | 10.910 | 0.50112 | 0.49997 | -0.00229 |
| 1.00 | 0.30 | 1.00 | 0.50 | 369.950 | 14.509 | 0.42661 | 0.42632 | -0.00067 |
| 0.80 | 0.30 | 1.00 | 0.50 | 370.212 | 14.026 | 0.42631 | 0.42065 | -0.01326 |
| 0.50 | 0.30 | 1.00 | 0.50 | 391.071 | 14.022 | 0.40357 | 0.40430 | 0.00181 |
| 0.30 | 0.30 | 1.00 | 0.50 | 417.531 | 16.399 | 0.37799 | 0.37769 | -0.00081 |
| 1.00 | 1.00 | 1.00 | 0.30 | 238.261 | 10.797 | 0.66240 | 0.66727 | 0.00736 |
| 0.80 | 1.00 | 1.00 | 0.30 | 240.860 | 11.032 | 0.65525 | 0.65349 | -0.00269 |
| 0.50 | 1.00 | 1.00 | 0.30 | 256.597 | 10.614 | 0.61507 | 0.61485 | -0.00035 |
| 0.30 | 1.00 | 1.00 | 0.30 | 283.046 | 12.202 | 0.55759 | 0.55534 | -0.00403 |
| 1.00 | 0.80 | 1.00 | 0.30 | 255.373 | 9.775 | 0.61801 | 0.61780 | -0.00034 |
| 0.80 | 0.80 | 1.00 | 0.30 | 259.813 | 8.873 | 0.60745 | 0.60597 | -0.00244 |
| 0.50 | 0.80 | 1.00 | 0.30 | 276.243 | 9.695 | 0.57132 | 0.57260 | 0.00224 |
| 0.30 | 0.80 | 1.00 | 0.30 | 304.458 | 12.528 | 0.51838 | 0.52065 | 0.00438 |
| 1.00 | 0.50 | 1.00 | 0.30 | 311.031 | 10.873 | 0.50742 | 0.50494 | -0.00490 |
| 0.80 | 0.50 | 1.00 | 0.30 | 318.653 | 11.660 | 0.49528 | 0.49701 | 0.00347 |
| 0.50 | 0.50 | 1.00 | 0.30 | 331.547 | 11.507 | 0.47602 | 0.47433 | -0.00355 |
| 0.30 | 0.50 | 1.00 | 0.30 | 360.829 | 12.542 | 0.43739 | 0.43812 | 0.00166 |
| 1.00 | 0.30 | 1.00 | 0.30 | 413.889 | 16.507 | 0.38132 | 0.38052 | -0.00211 |
| 0.80 | 0.30 | 1.00 | 0.30 | 417.046 | 15.533 | 0.37843 | 0.37599 | -0.00645 |
| 0.50 | 0.30 | 1.00 | 0.30 | 433.200 | 17.662 | 0.36432 | 0.36287 | -0.00397 |
| 0.30 | 0.30 | 1.00 | 0.30 | 465.502 | 18.800 | 0.33904 | 0.34129 | 0.00664 |

[a]No variation in driver performance.

## APPENDIX E

## SELECTED PLOTS OF CREW PERFORMANCE VERSUS CREWMEMBER PERFORMANCE

This appendix contains graphs (Figs. 10 through 13) of crew performance as a function of individual crewmember performance for the four crew types.* Each graph is a "slice" through the four-dimensional performance surface given by Eq. (9). In each case the performance level of two crewmembers is held constant at the values indicated on the graph. The performance level of a third crewmember is the independent variable, ranging from 1 to 0. The four curves correspond to performance levels of 0.3, 0.5, 0.8, and 1.0 for the fourth crewmember whose symbol does not appear in the frame.

---

*In these plots, the crewmember titles are abbreviated as:

A = Assistant gunner
C' = Computer
C = Chief of section
D = Driver
F = Fire direction officer
G = Gunner
H = Horizontal control operator
L = Loader
S = Squad leader
T = Tank commander

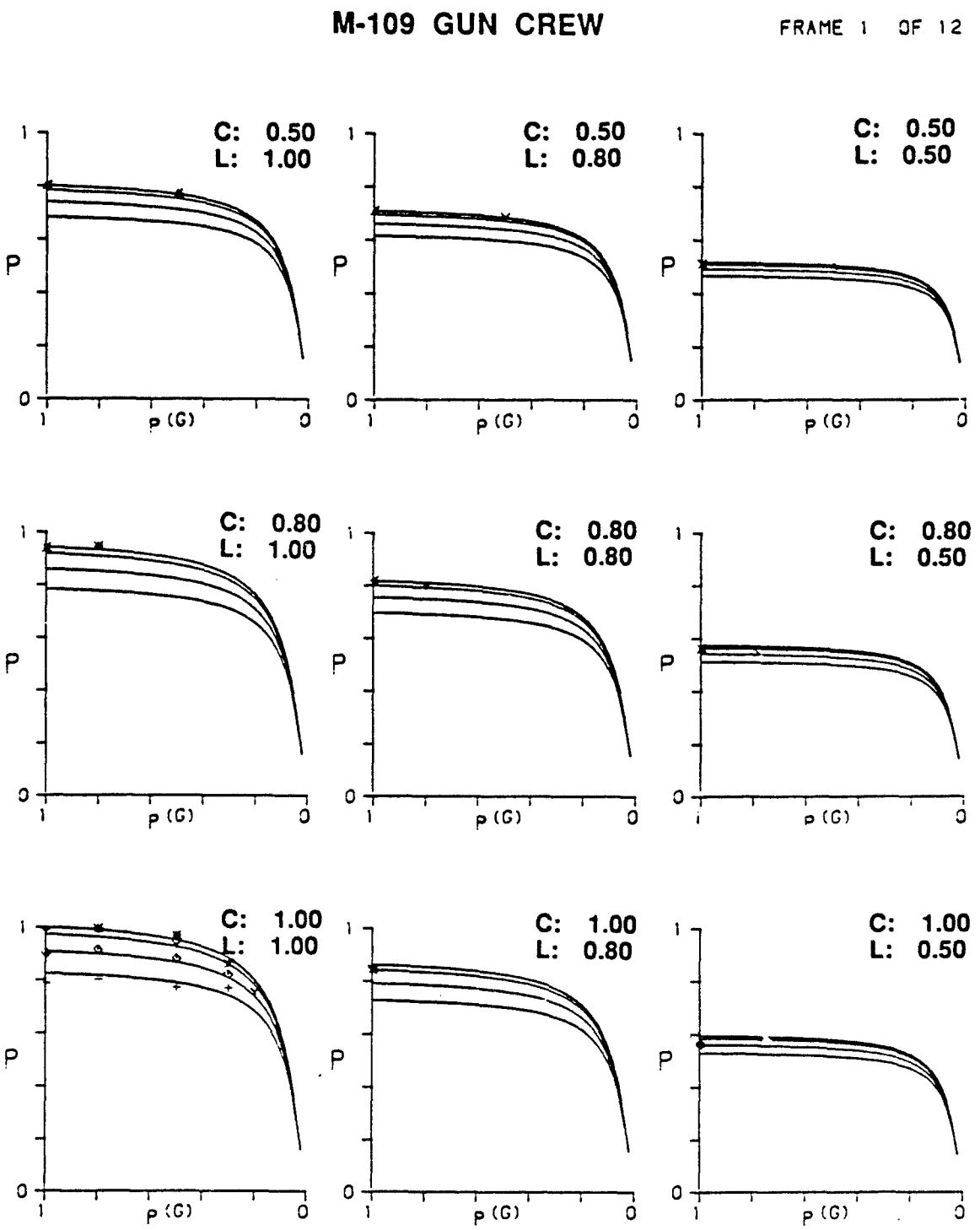



Figure 10. Final performance plot for gun crew.

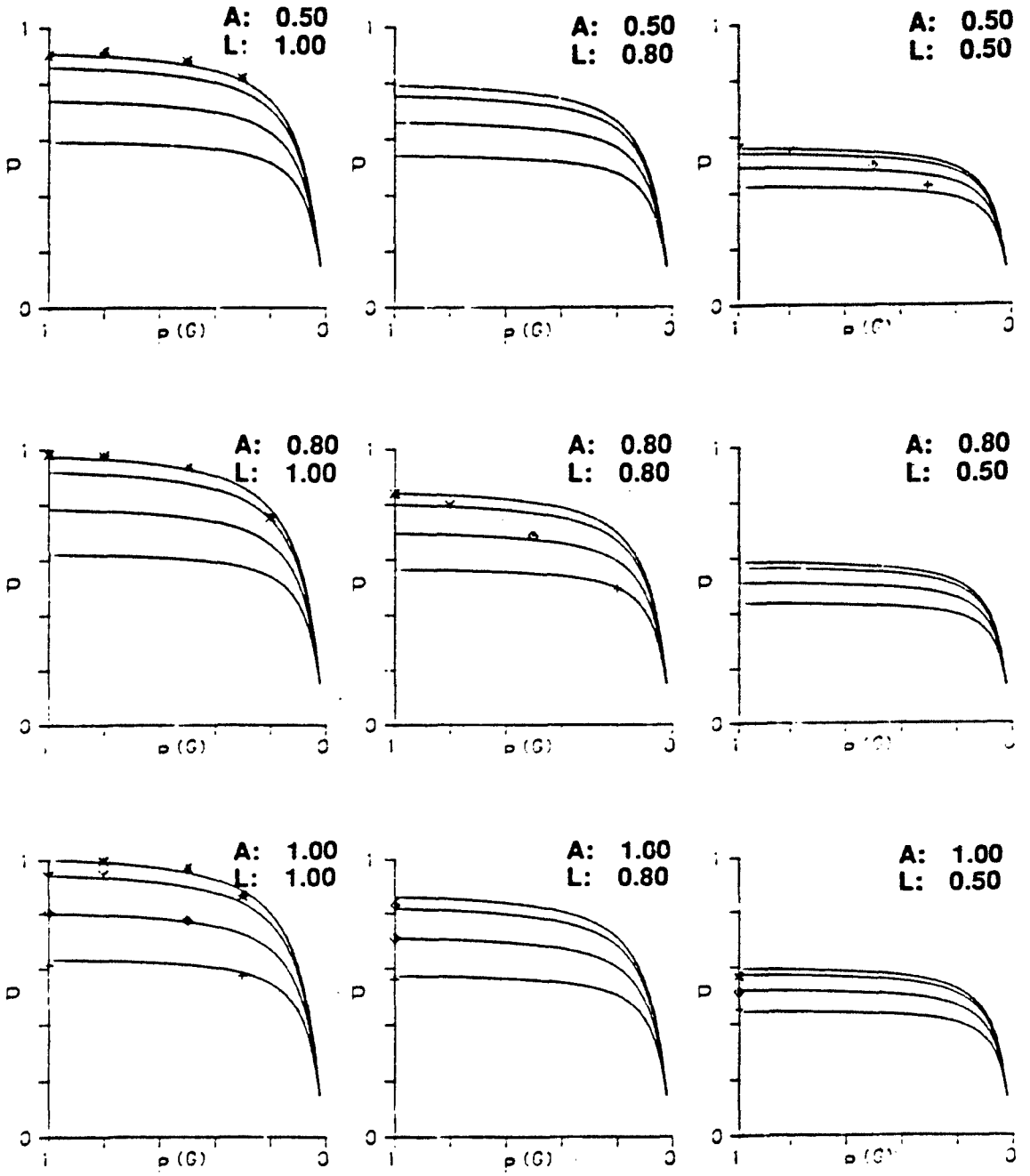



Figure 10. Final performance plot for gun crew (continued).

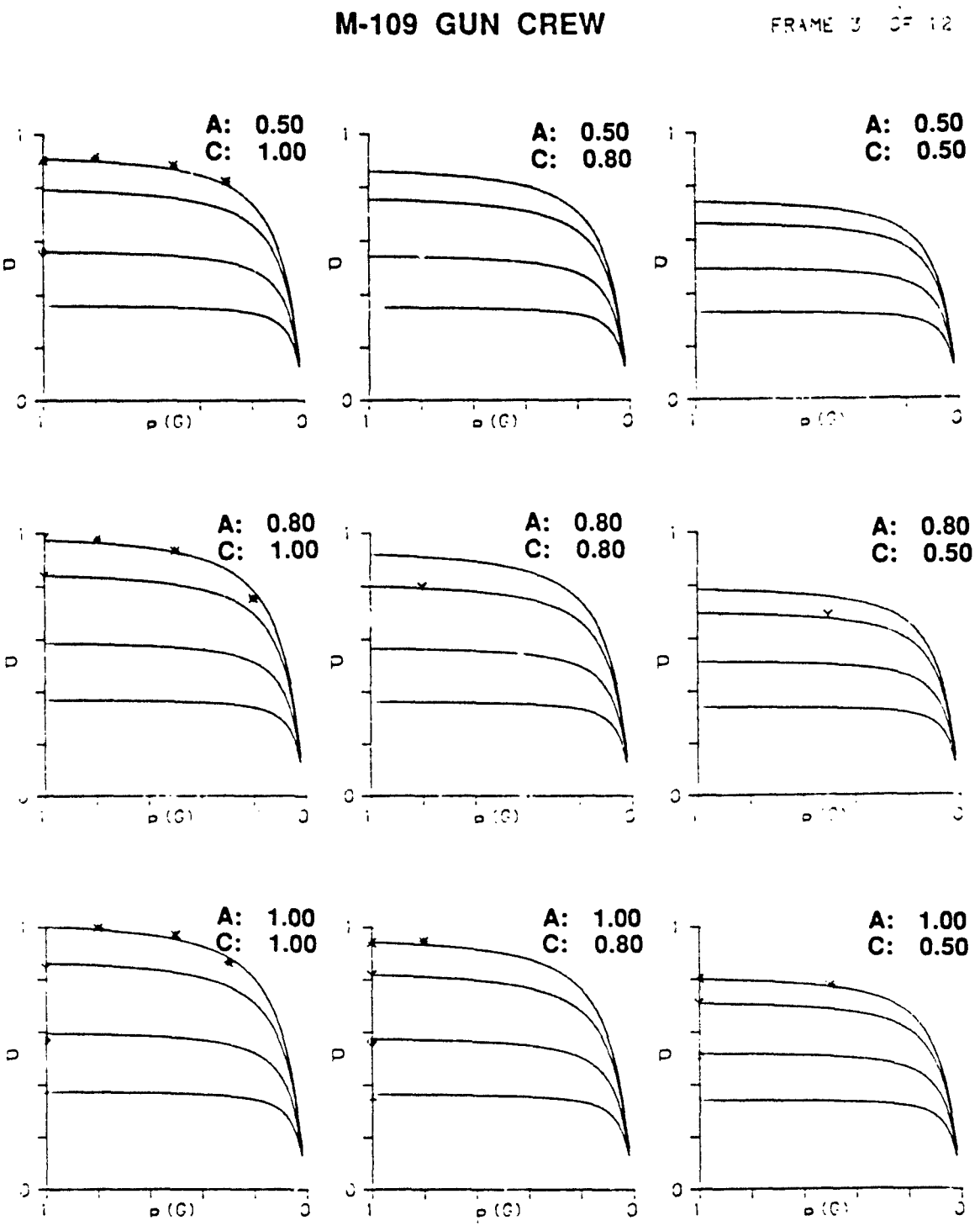



Figure 10. Final performance plot for gun crew (continued).

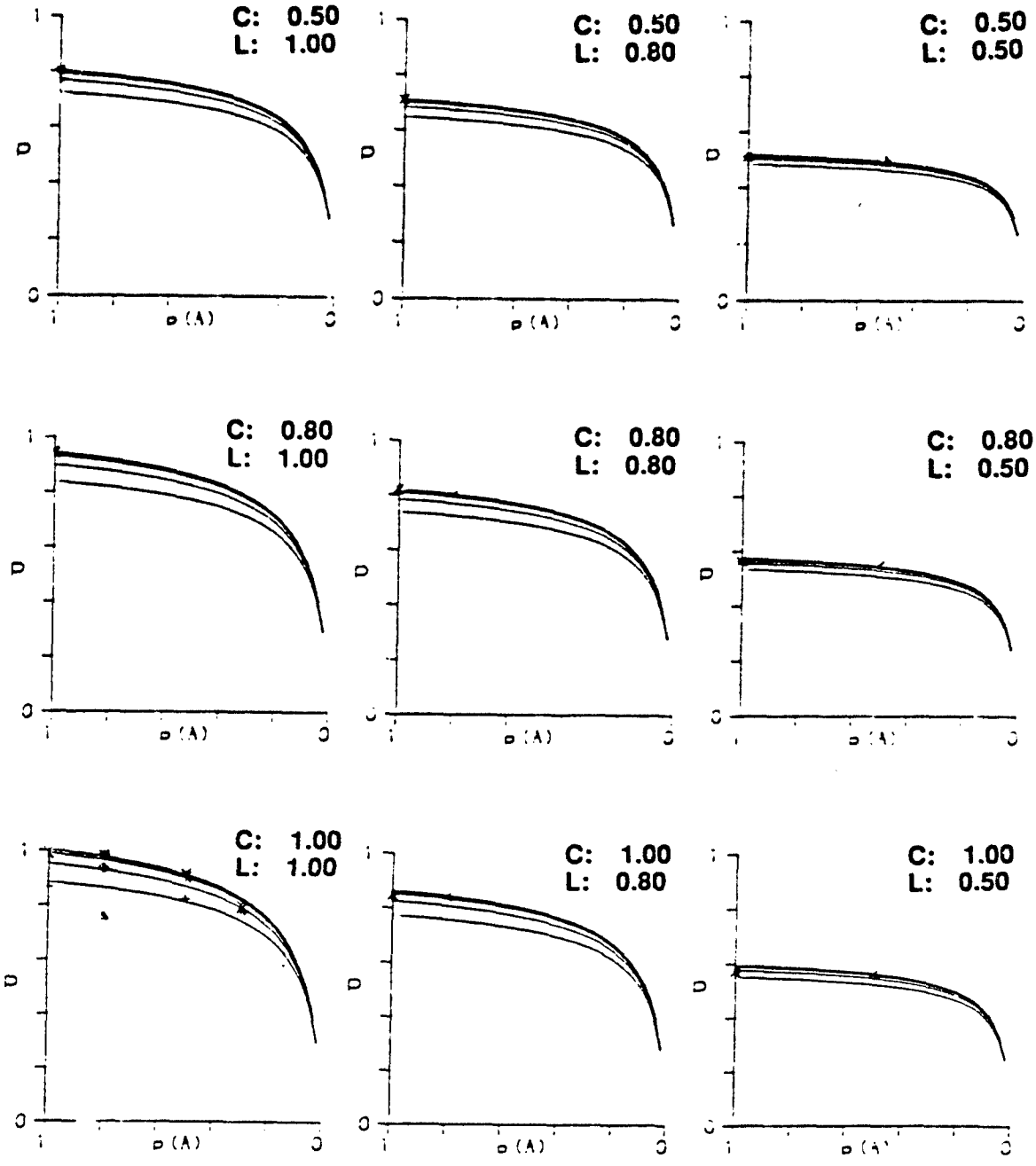



Figure 10. Final performance plot for gun crew (continued).

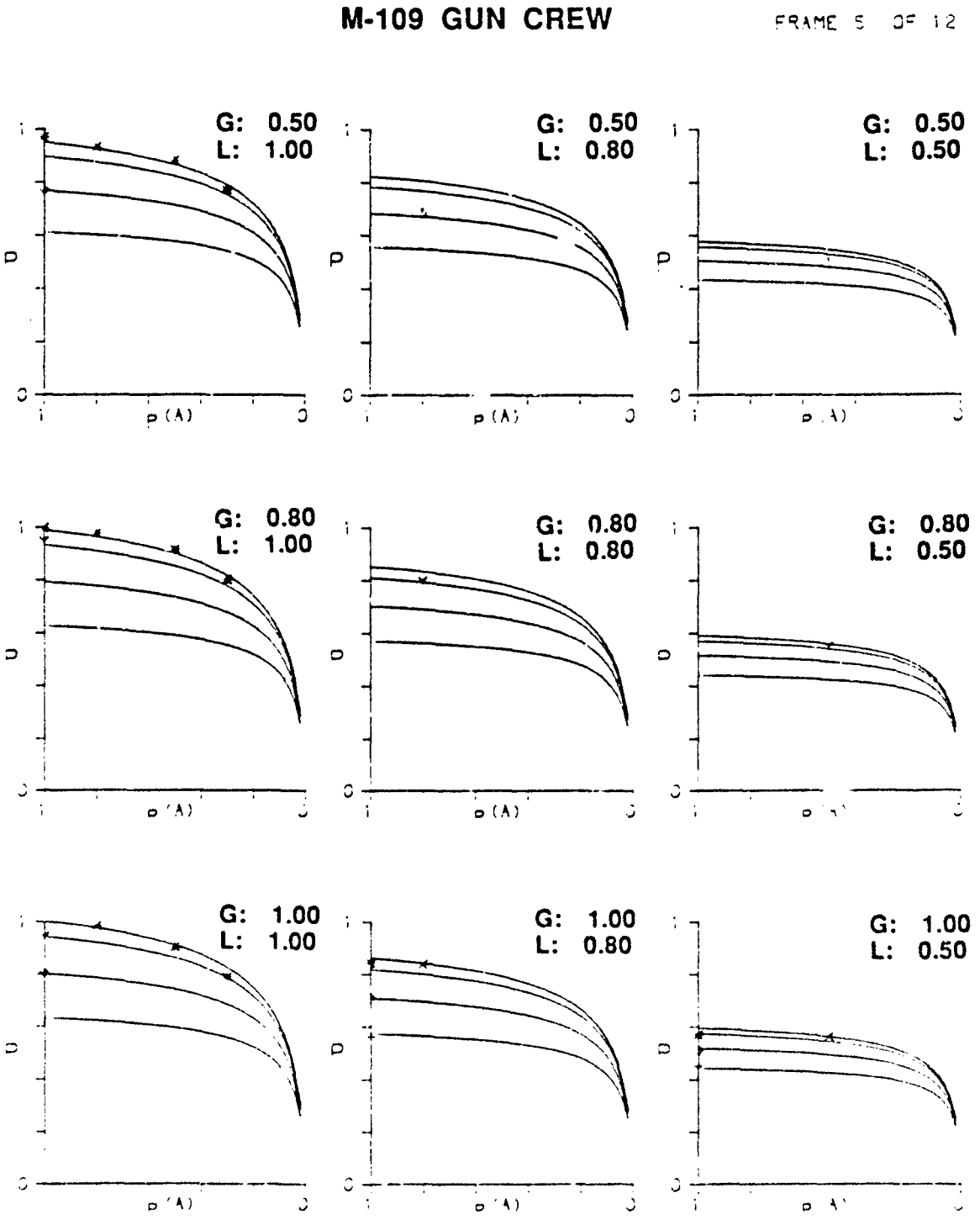



Figure 10. Final performance plot for gun crew (continued).

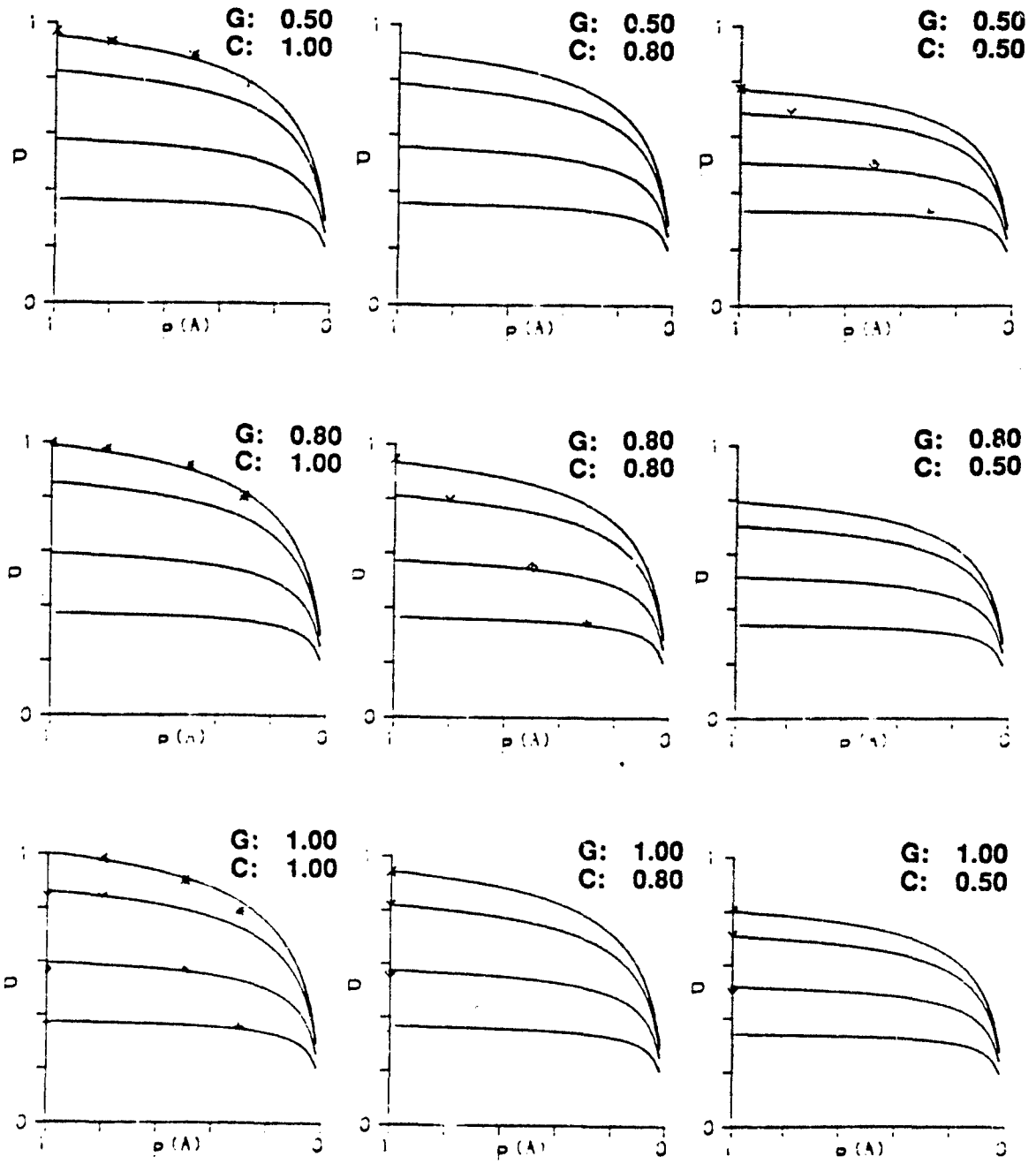



Figure 10. Final performance plot for gun crew (continued).

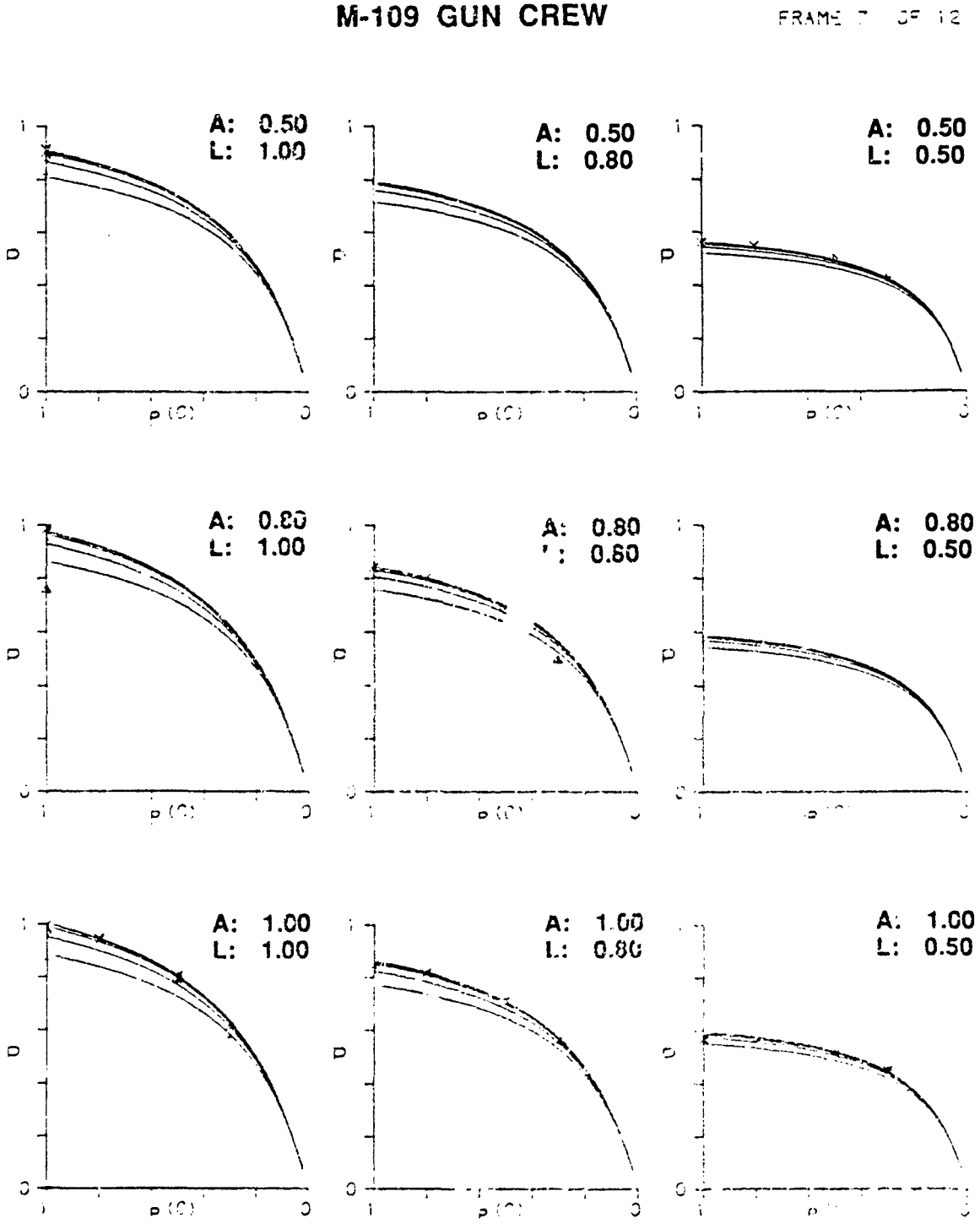



Figure 10. Final performance plot for gun crew (continued).

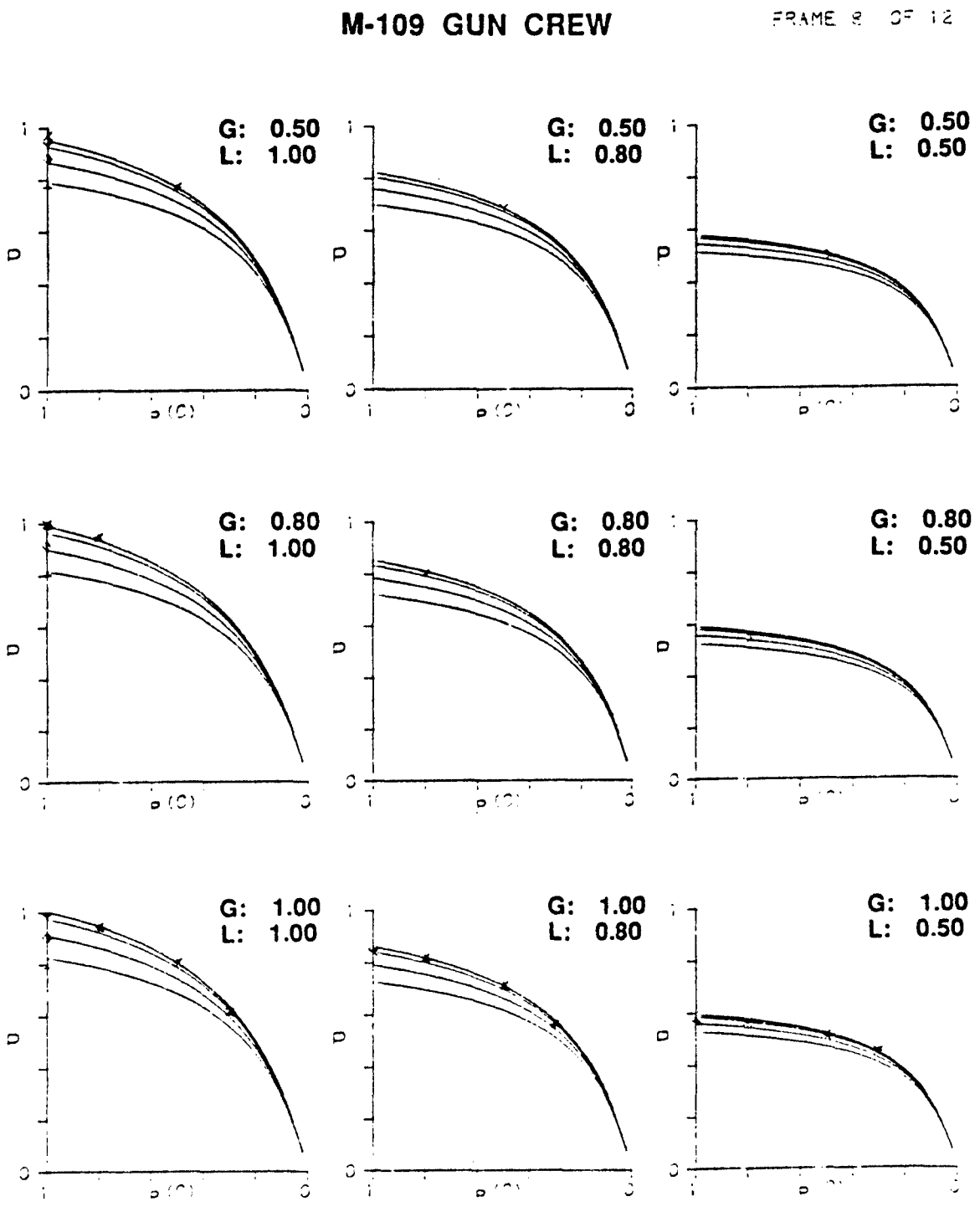



Figure 10. Final performance plot for gun crew (continued).

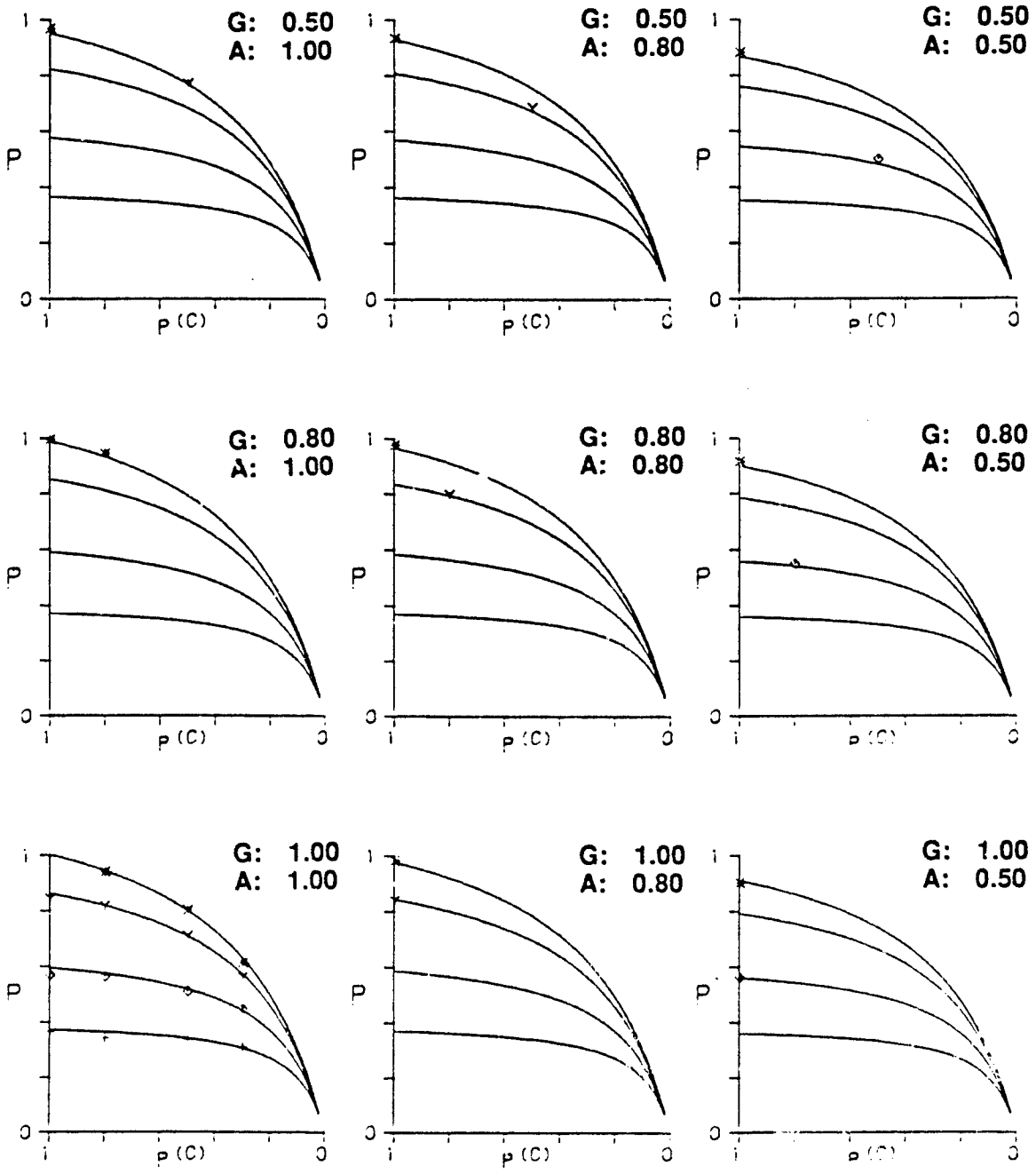



Figure 10. Final performance plot for gun crew (continued).

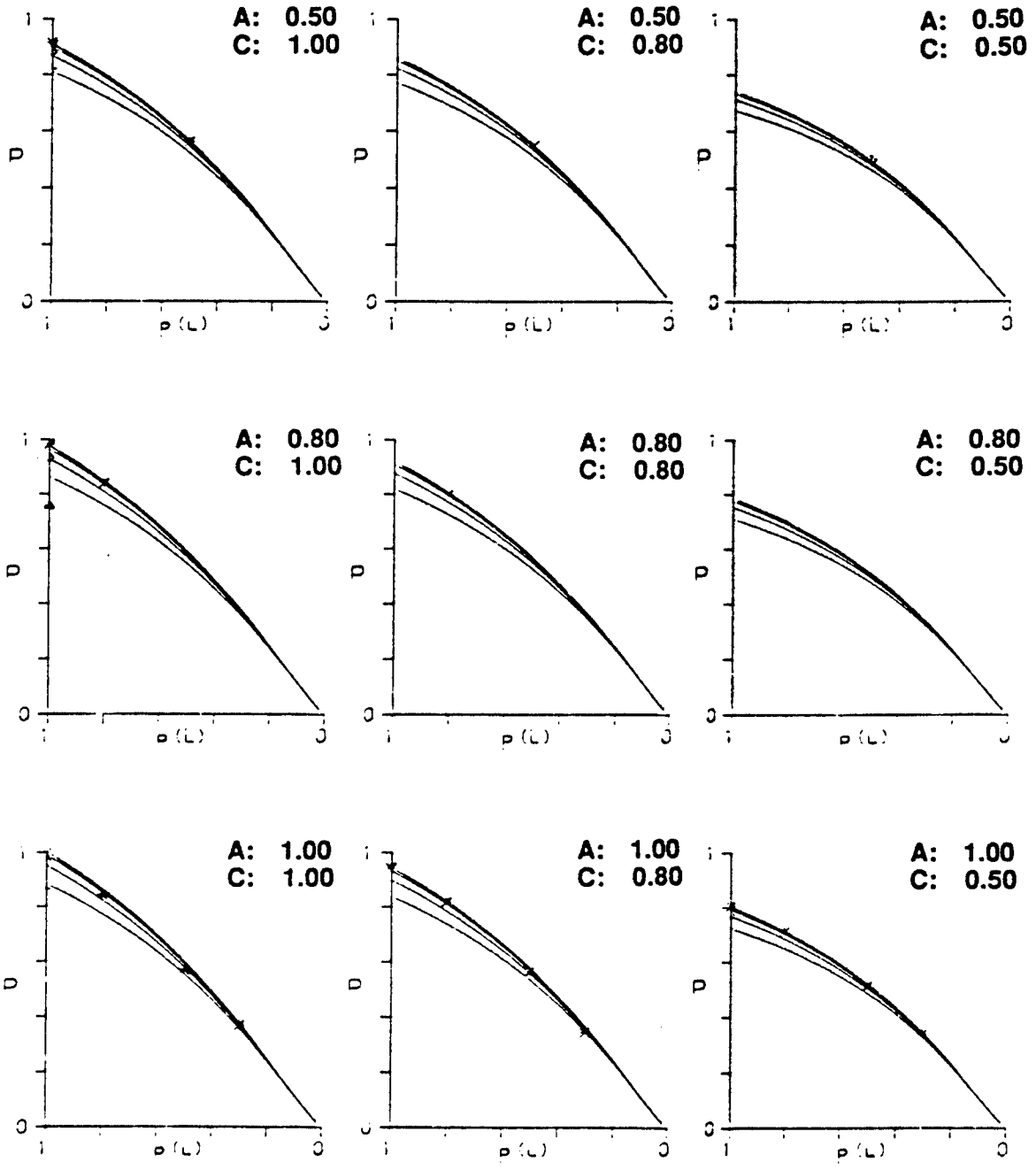



Figure 10. Final performance plot for gun crew (continued).

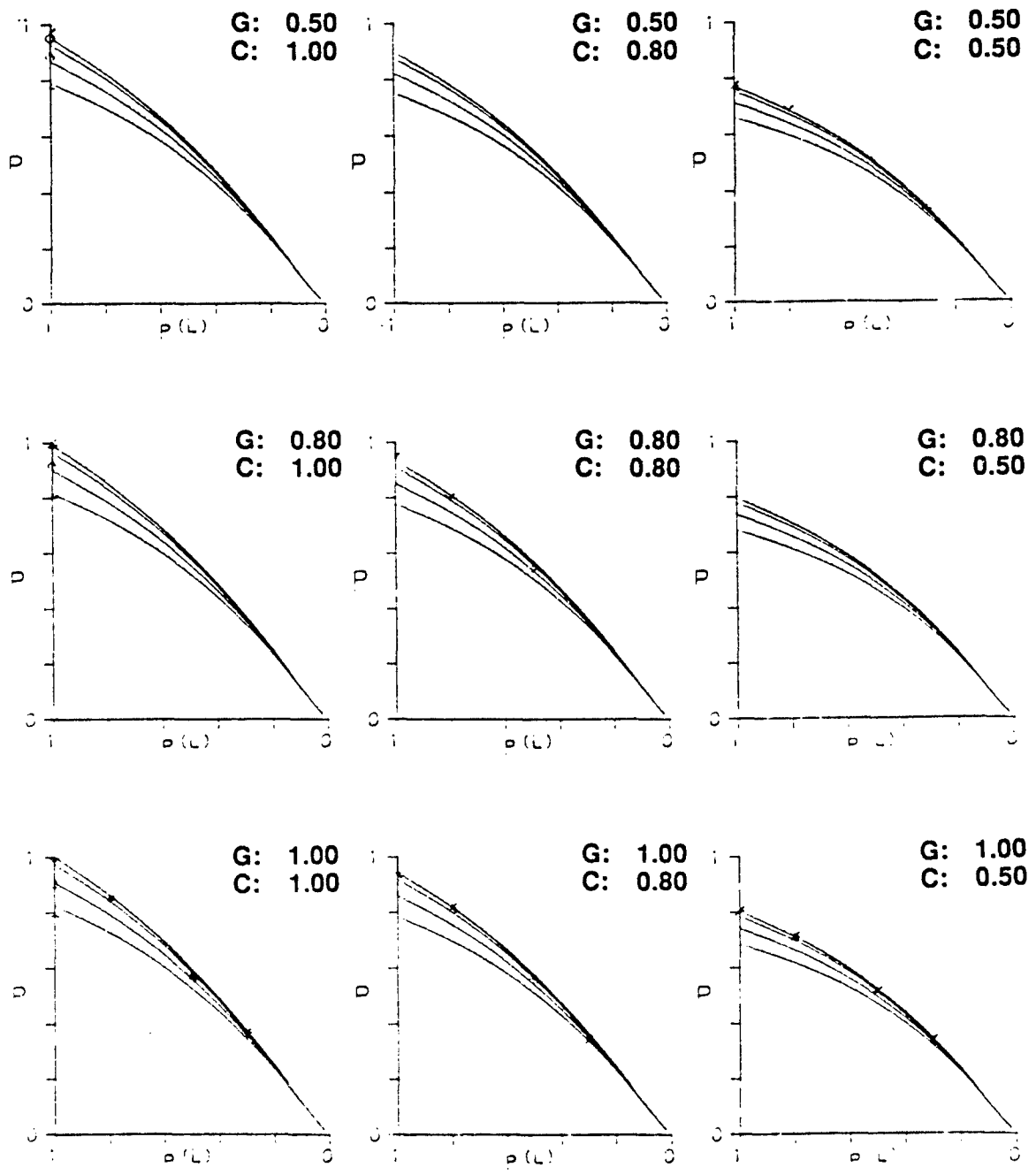



Figure 10. Final performance plot for gun crew (continued).

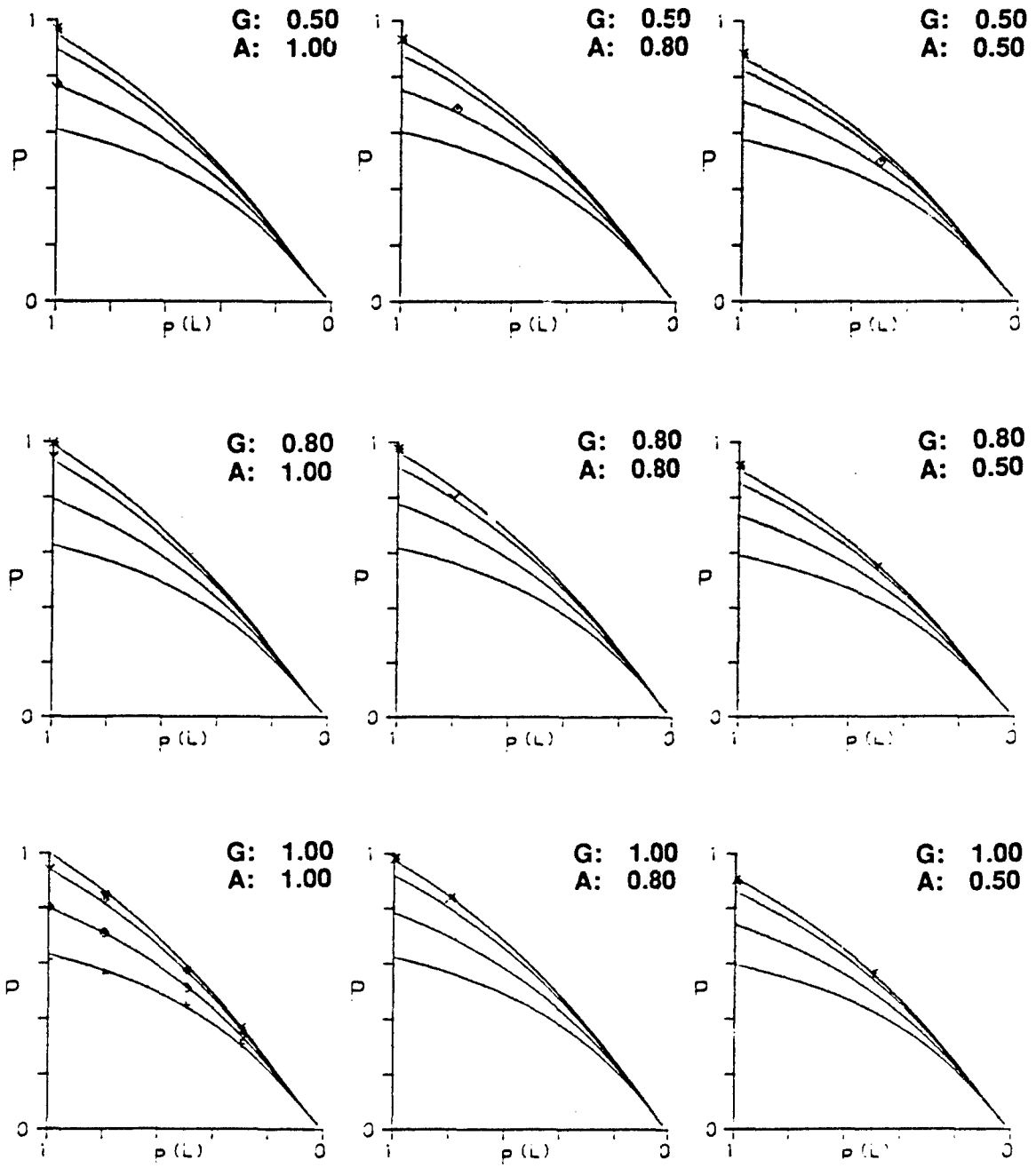



Figure 10. Final performance plot for gun crew (continued).

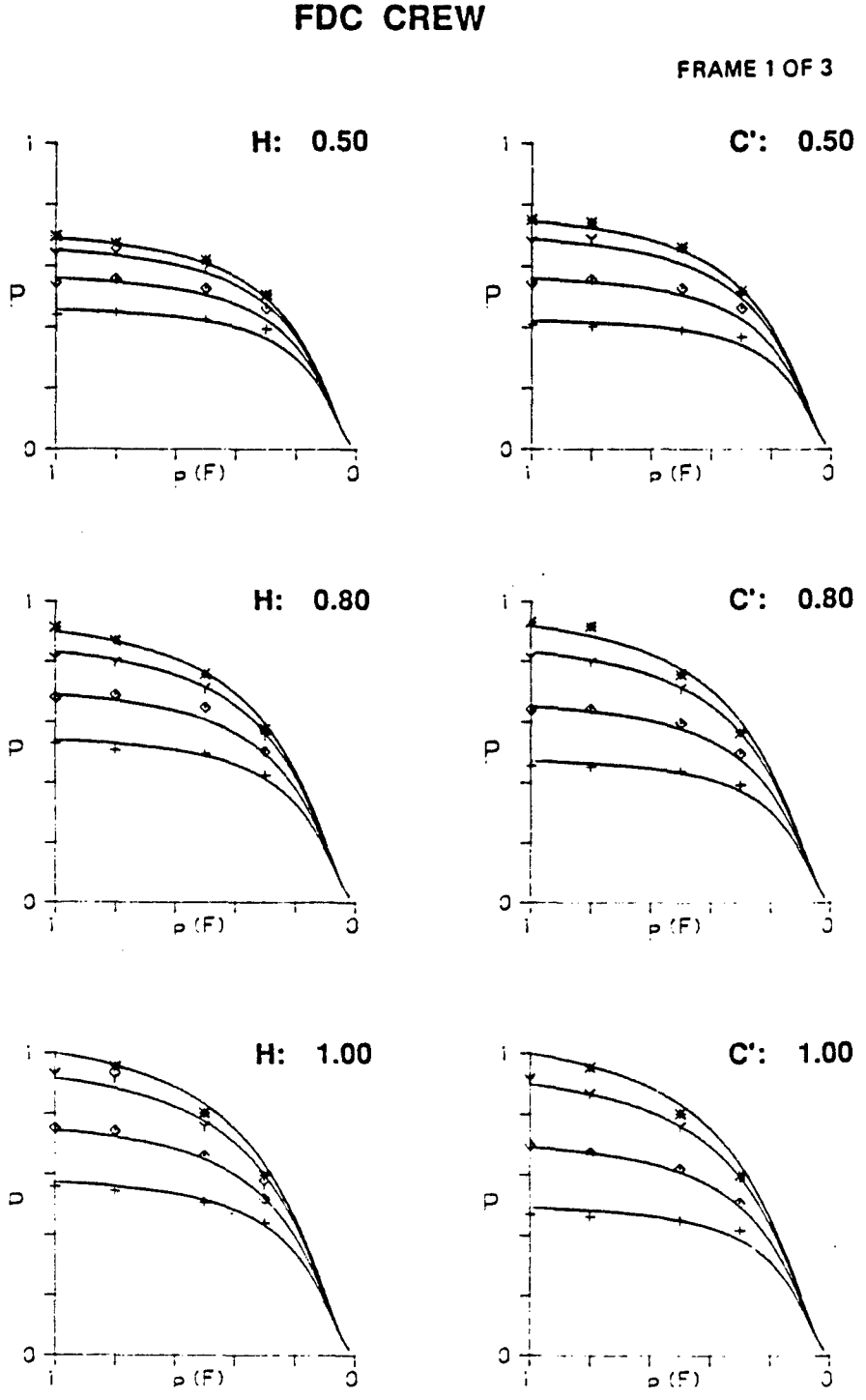



Figure 11. Final performance plot for FDC crew.

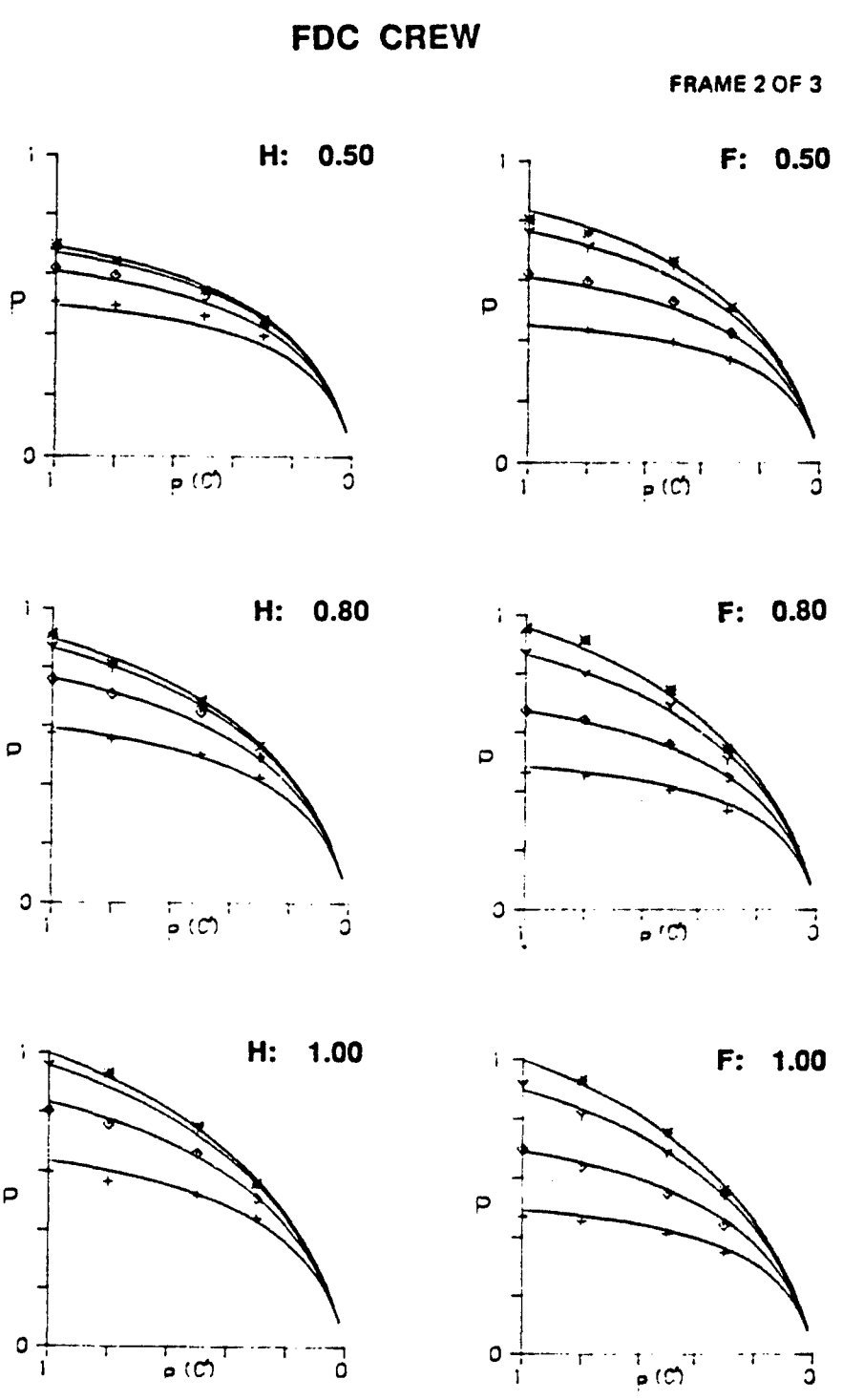



Figure 11. Final performance plot for FDC crew (continued).

## FDC CREW

FRAME 3 OF 3

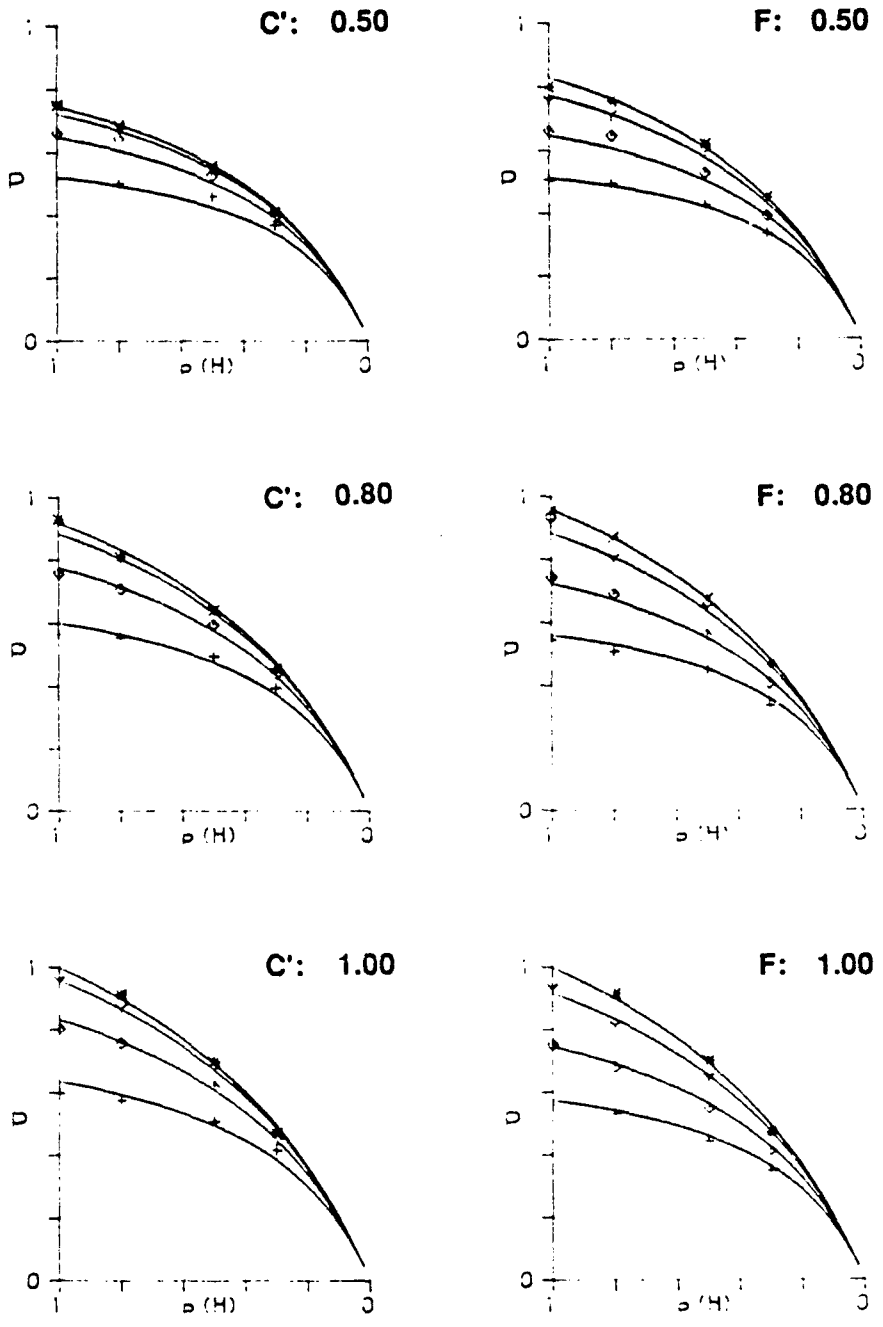



Figure 11. Final performance plot for FDC crew (continued).

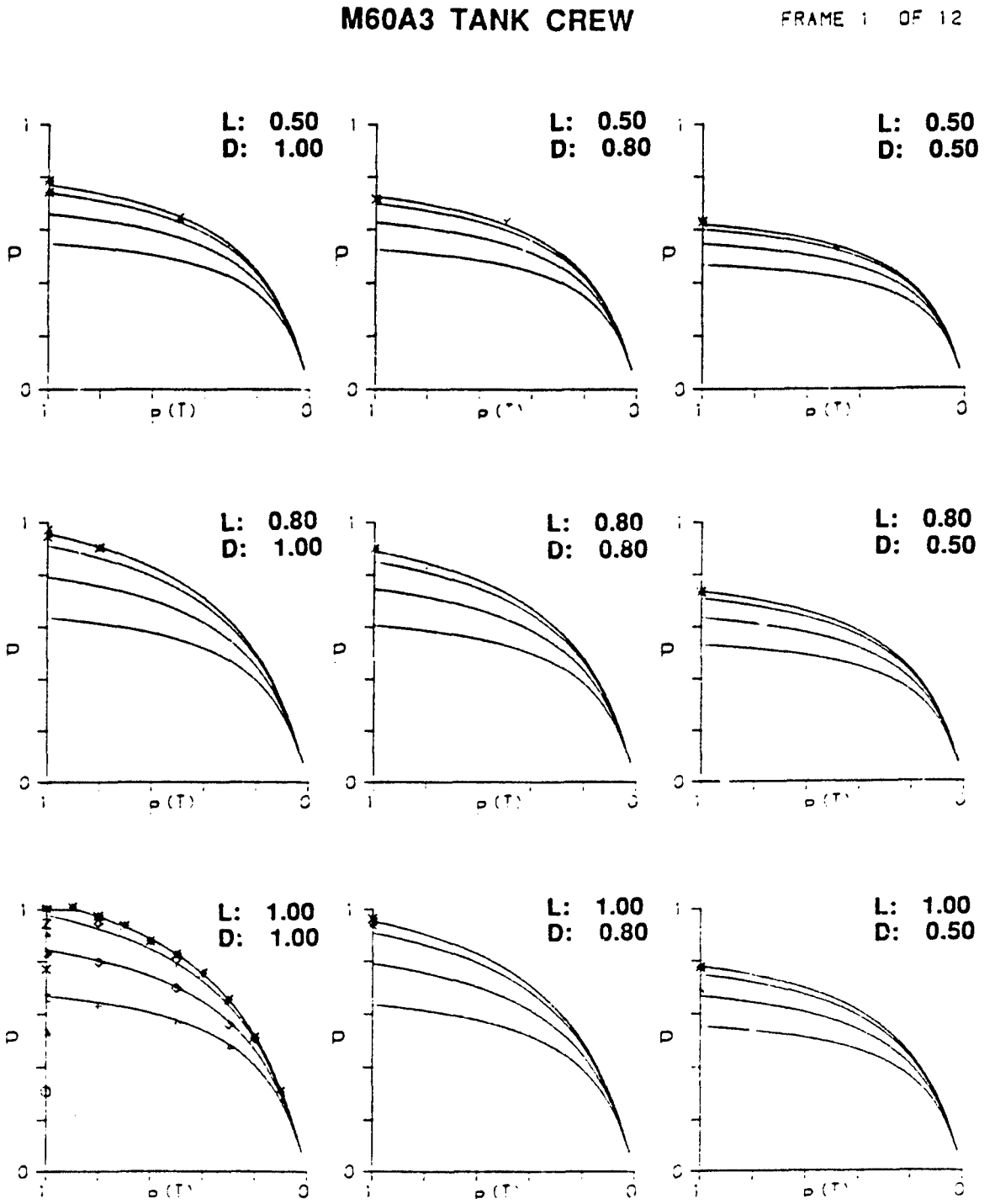



Figure 12. Final performance plot for tank crew.

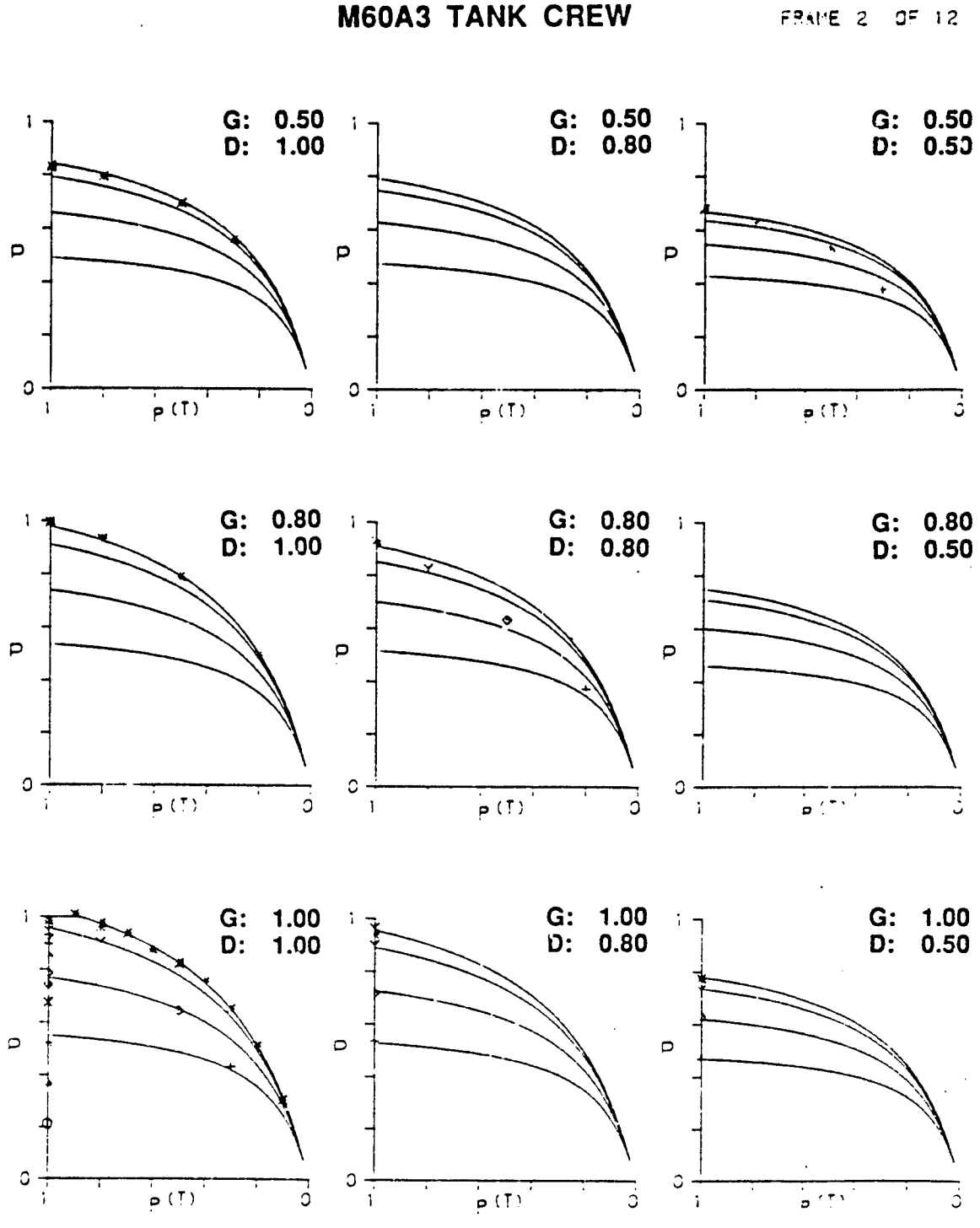



Figure 12. Final performance plot for tank crew (continued).

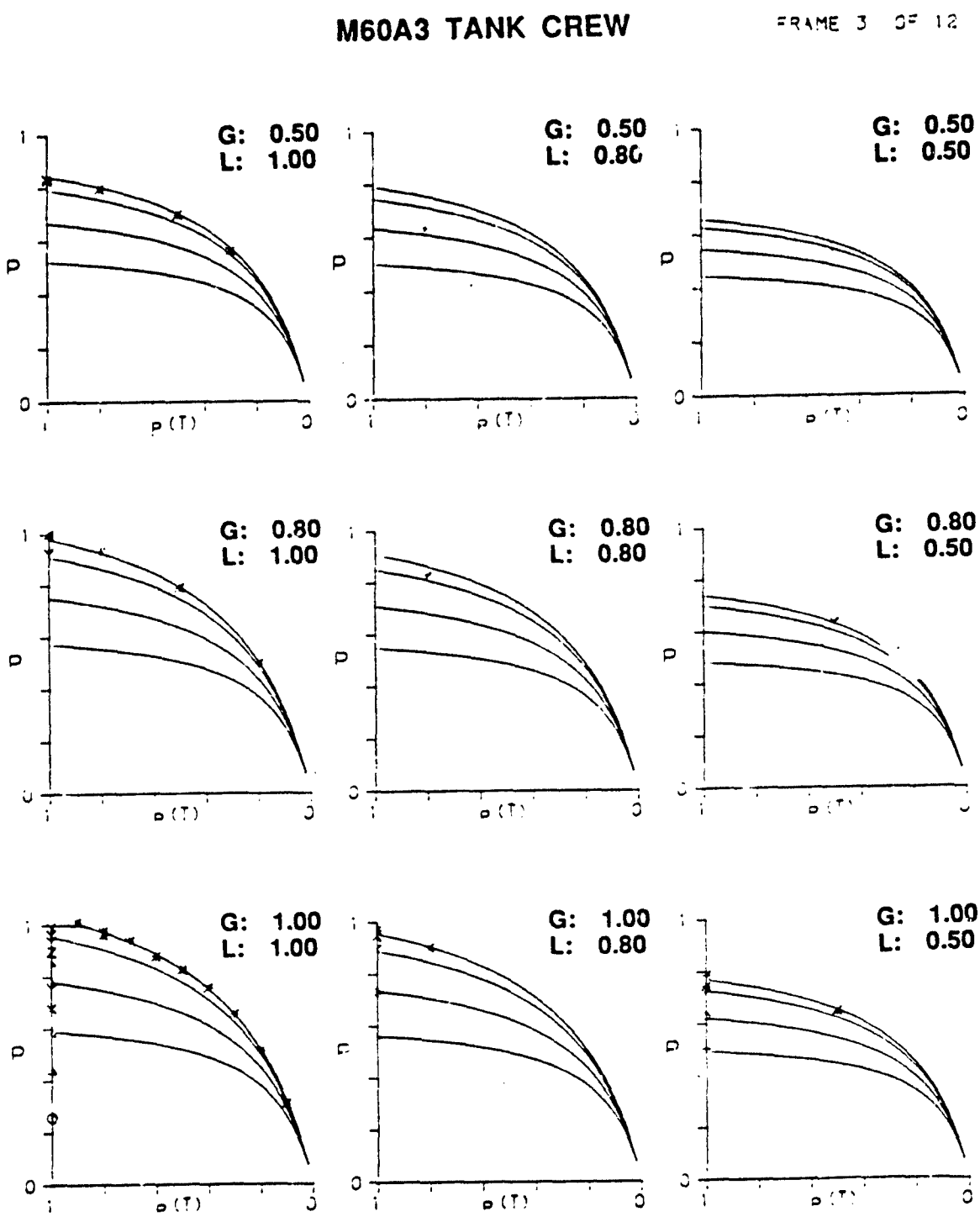



Figure 12. Final performance plot for tank crew (continued).

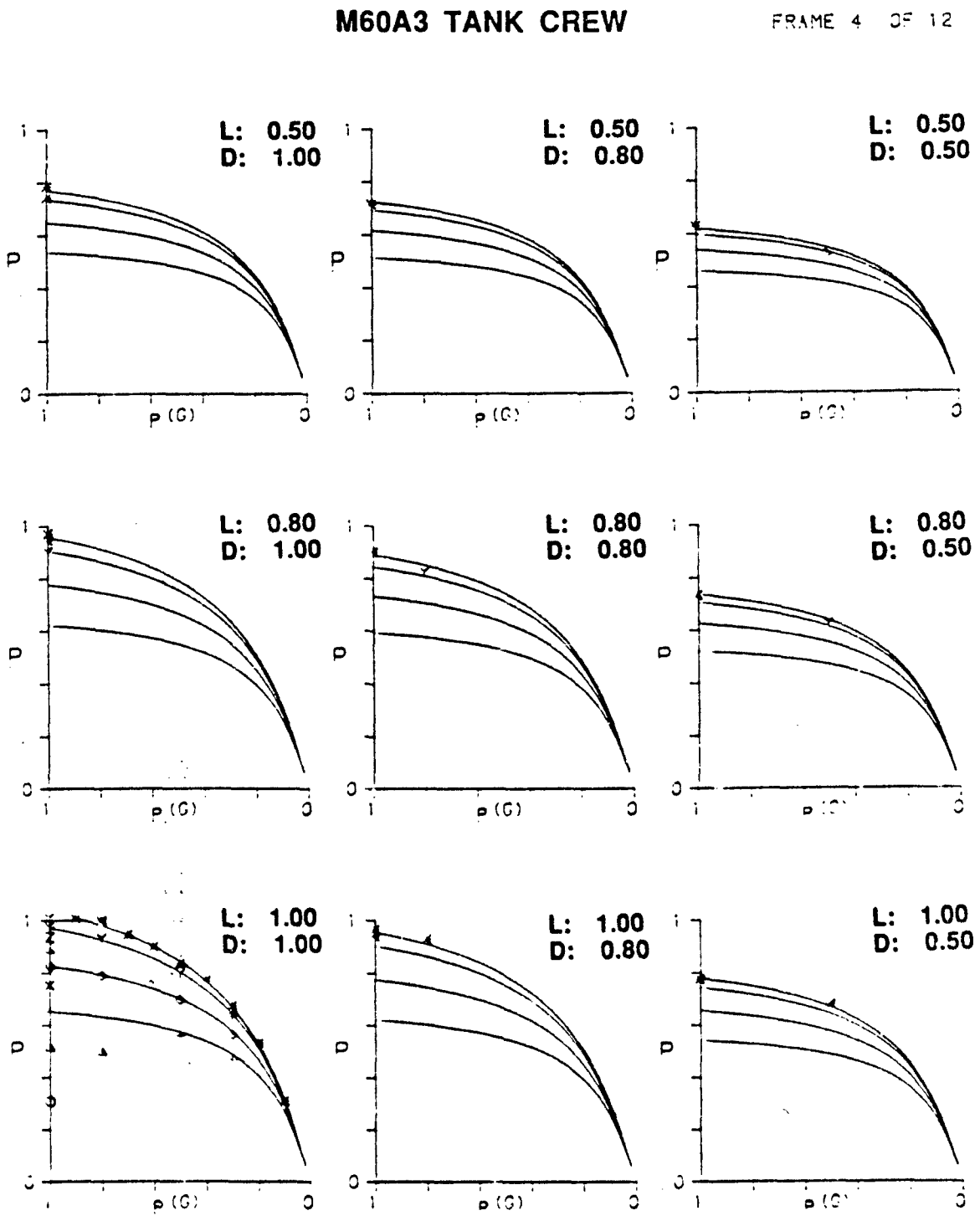



Figure 12. Final performance plot for tank crew (continued).

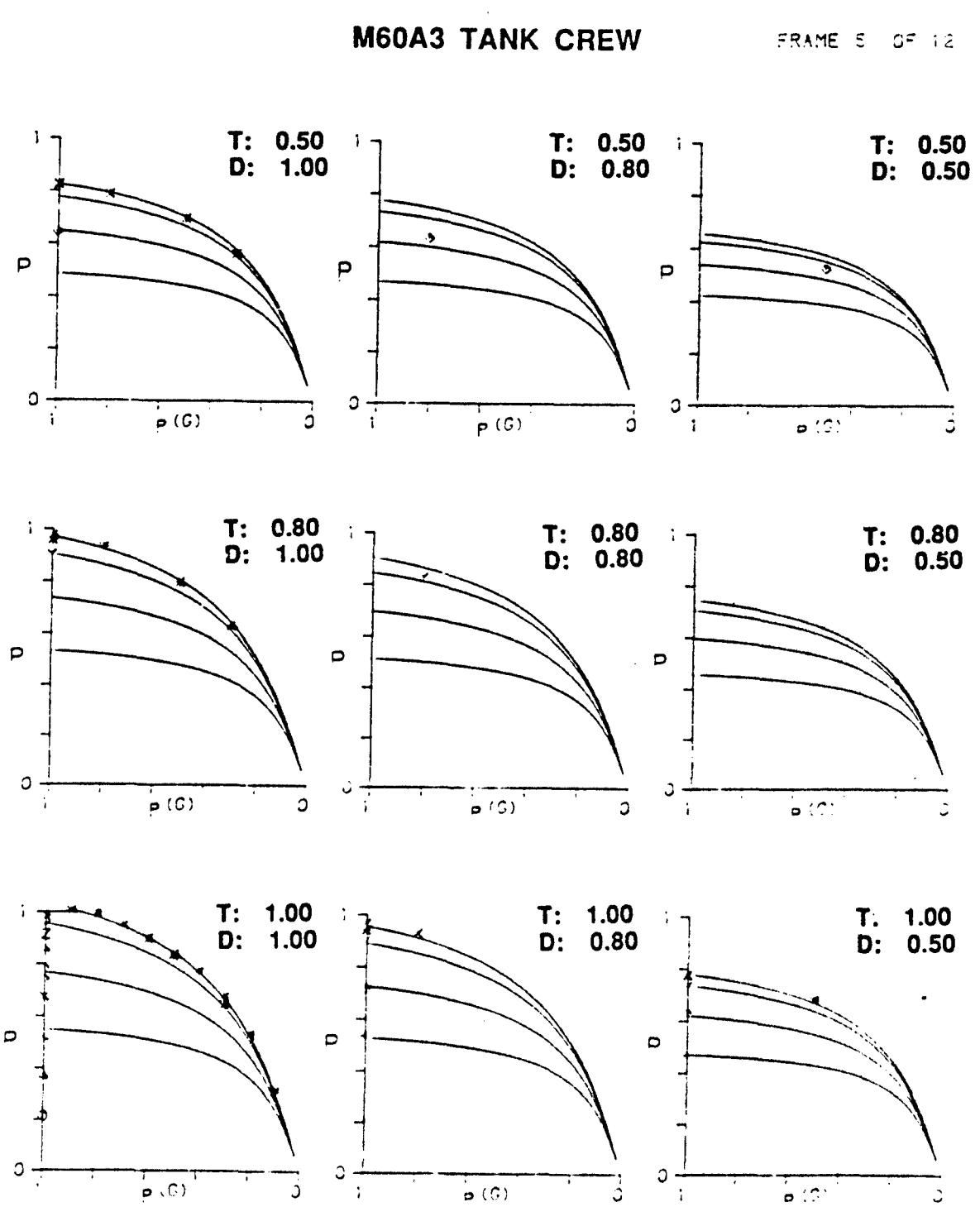



Figure 12. Final performance plot for tank crew (continued).

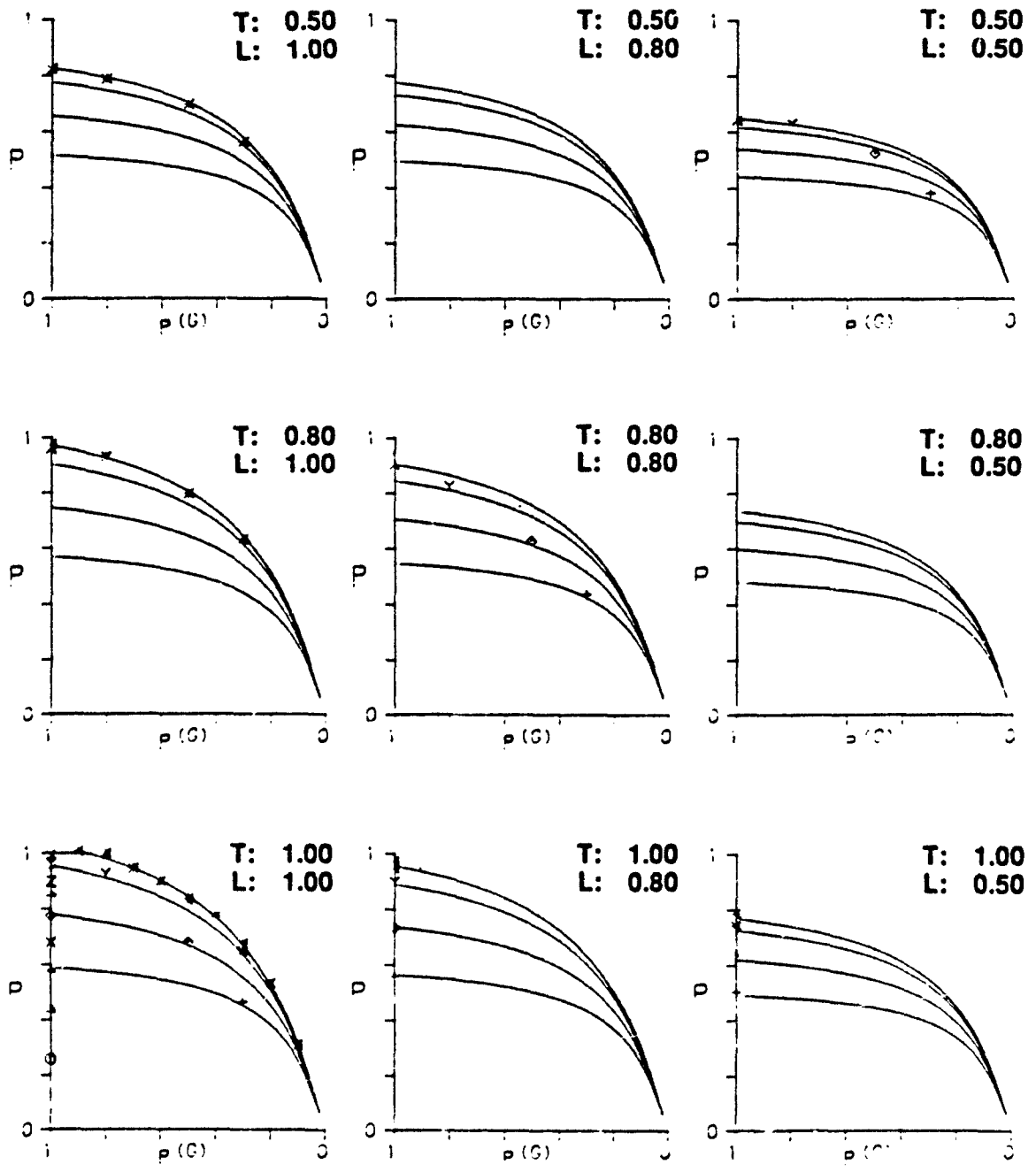



Figure 12. Final performance plot for tank crew (continued).

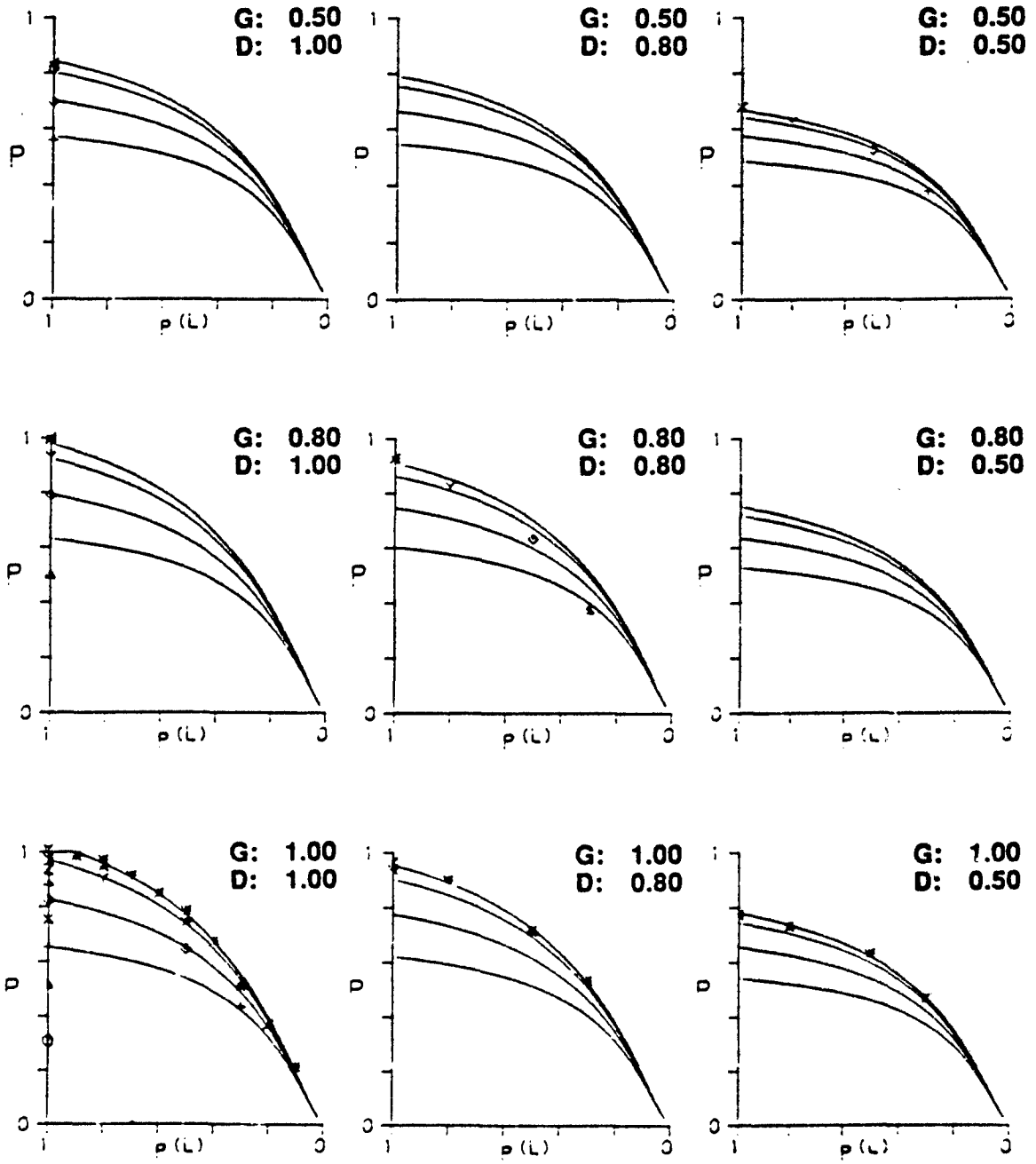



Figure 12. Final performance plot for tank crew (continued).

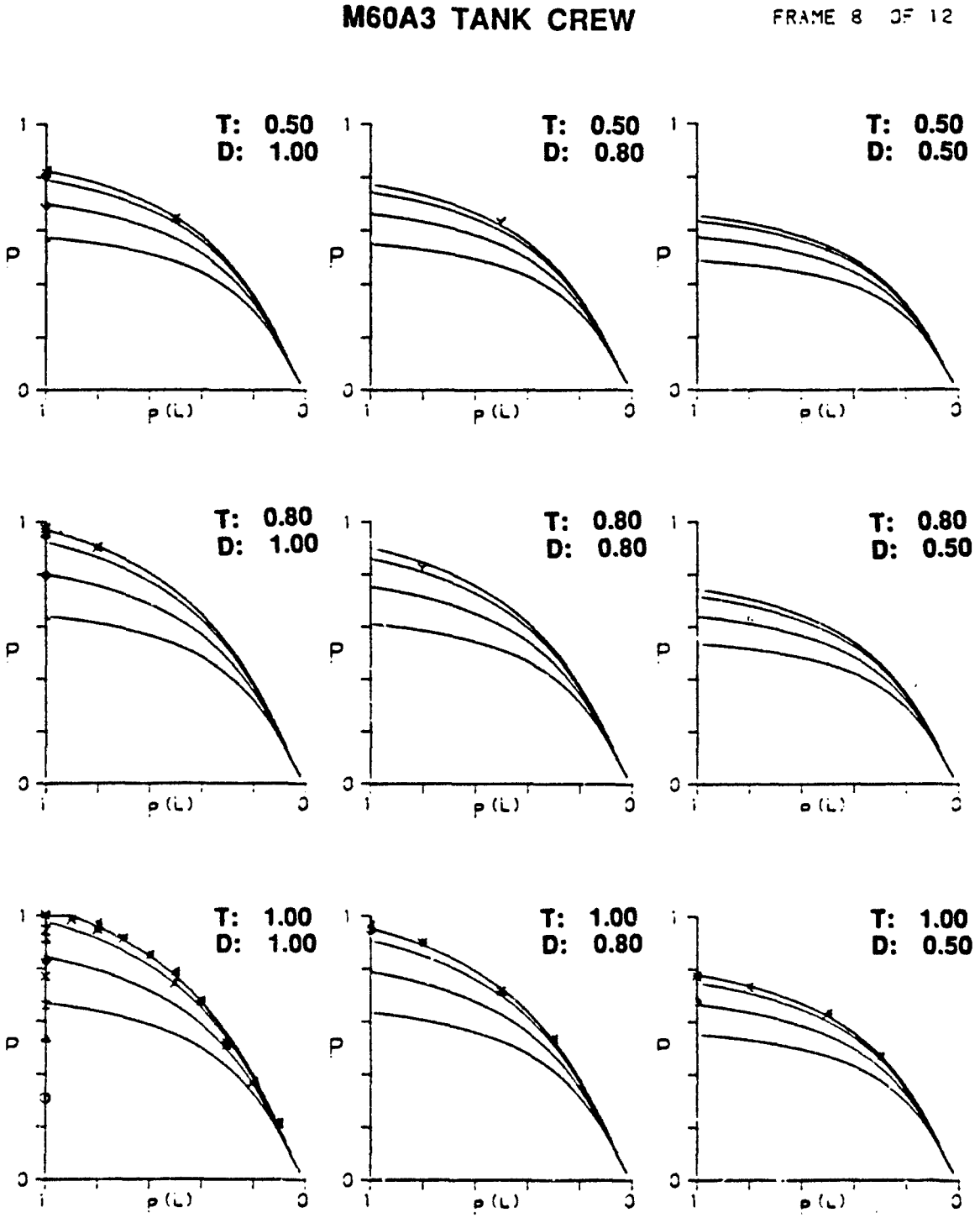



Figure 12. Final performance plot for tank crew (continued).

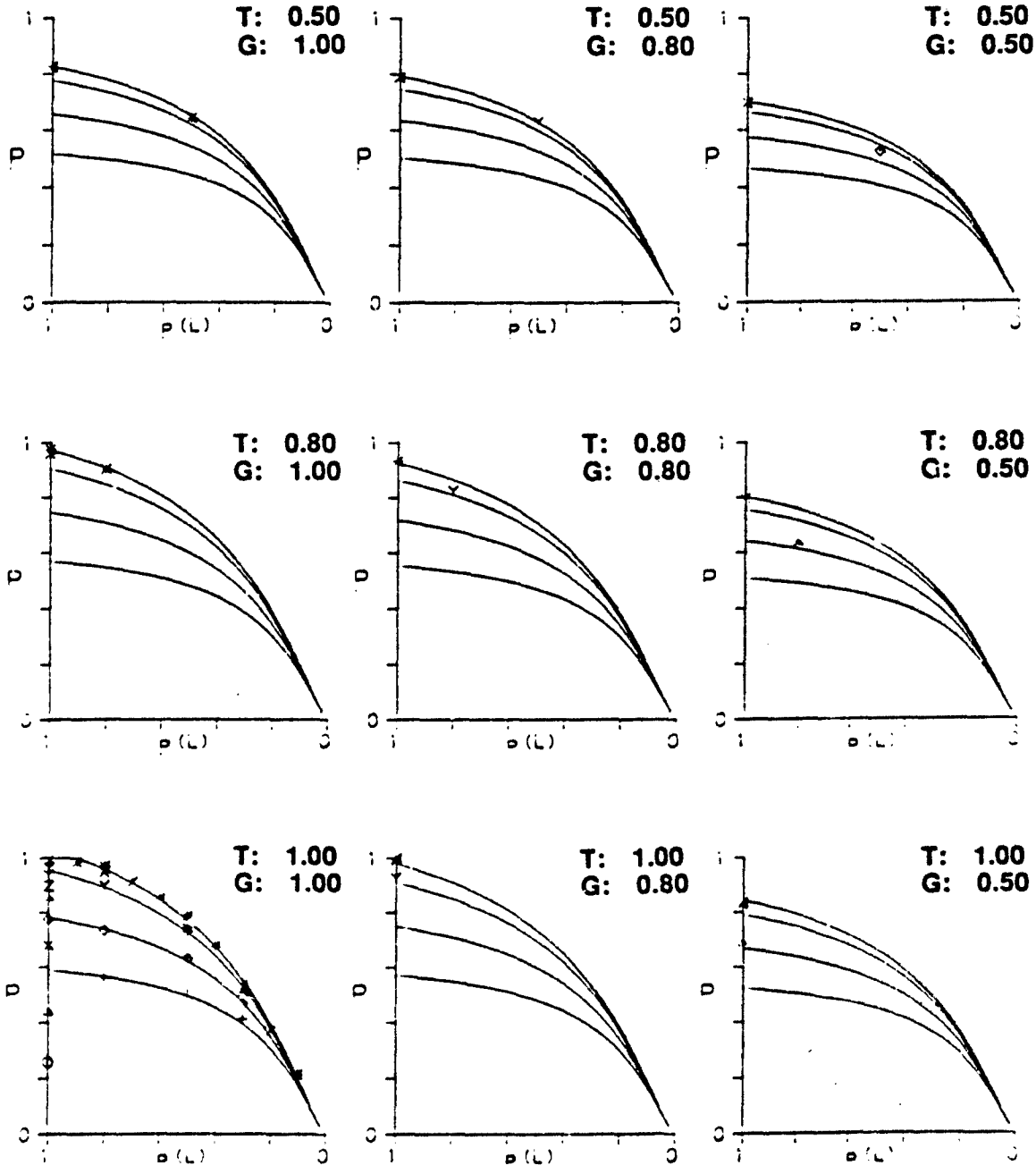



Figure 12. Final performance plot for tank crew (continued).

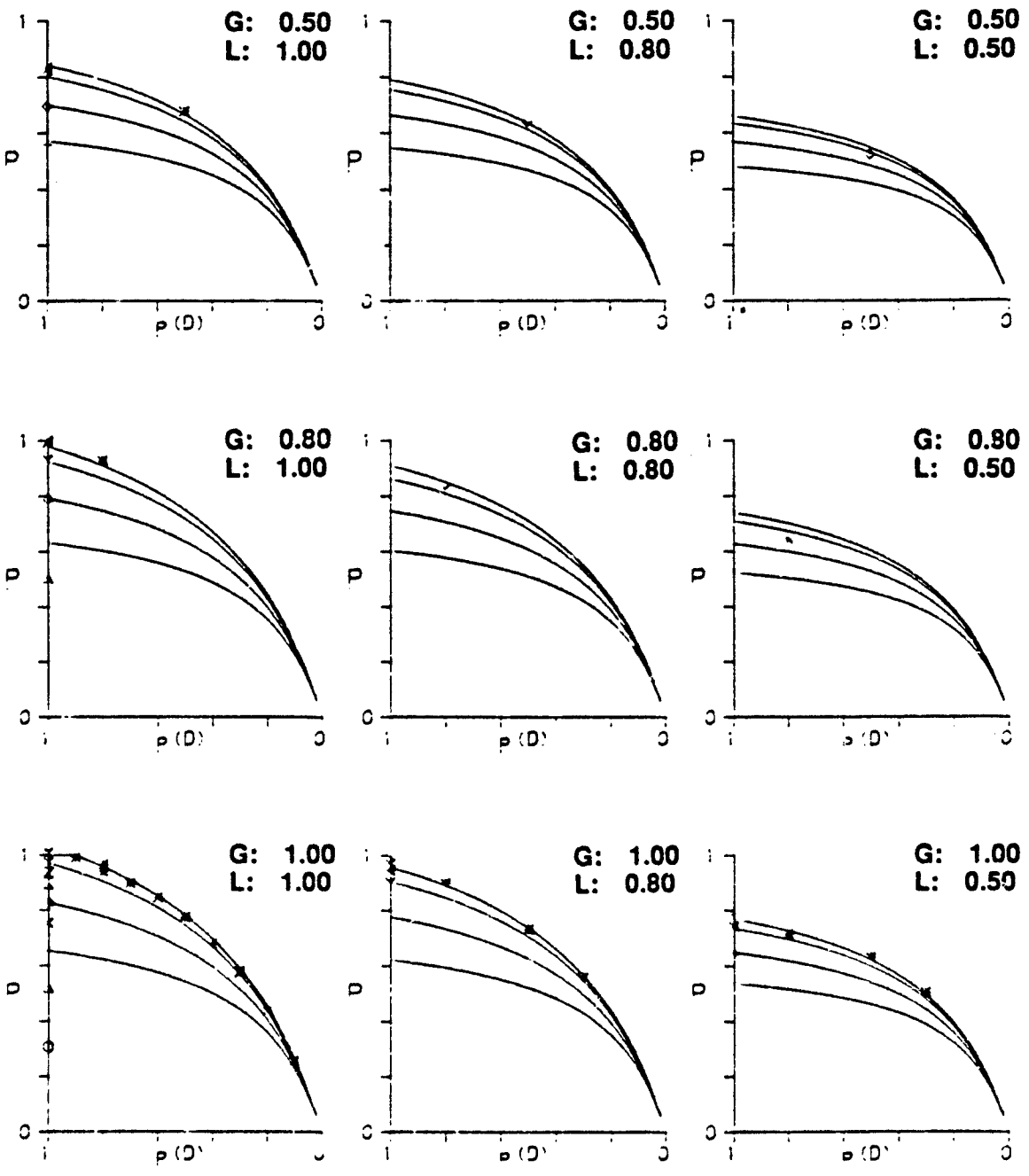



Figure 12. Final performance plot for tank crew (continued).

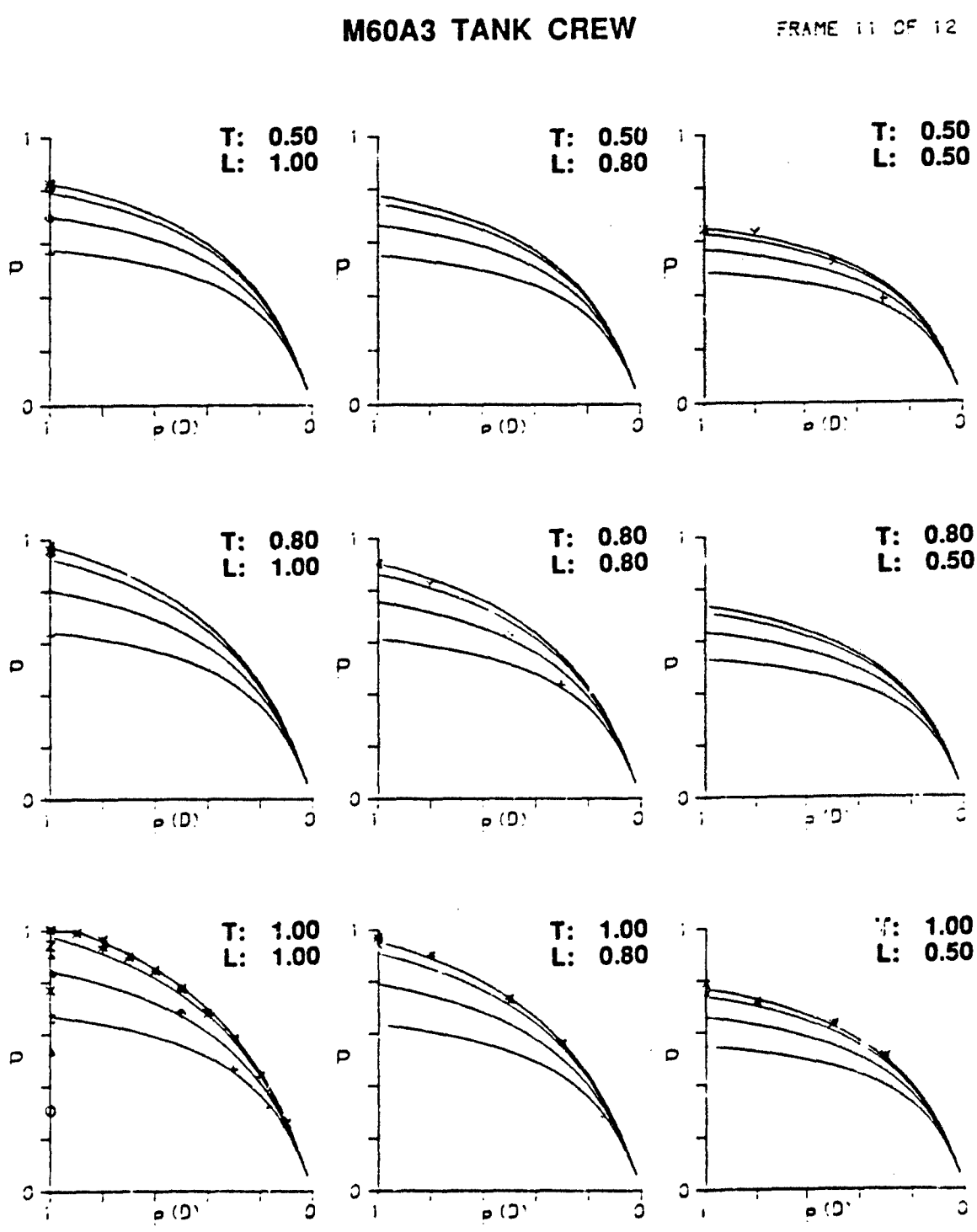



Figure 12. Final performance plot for tank crew (continued).

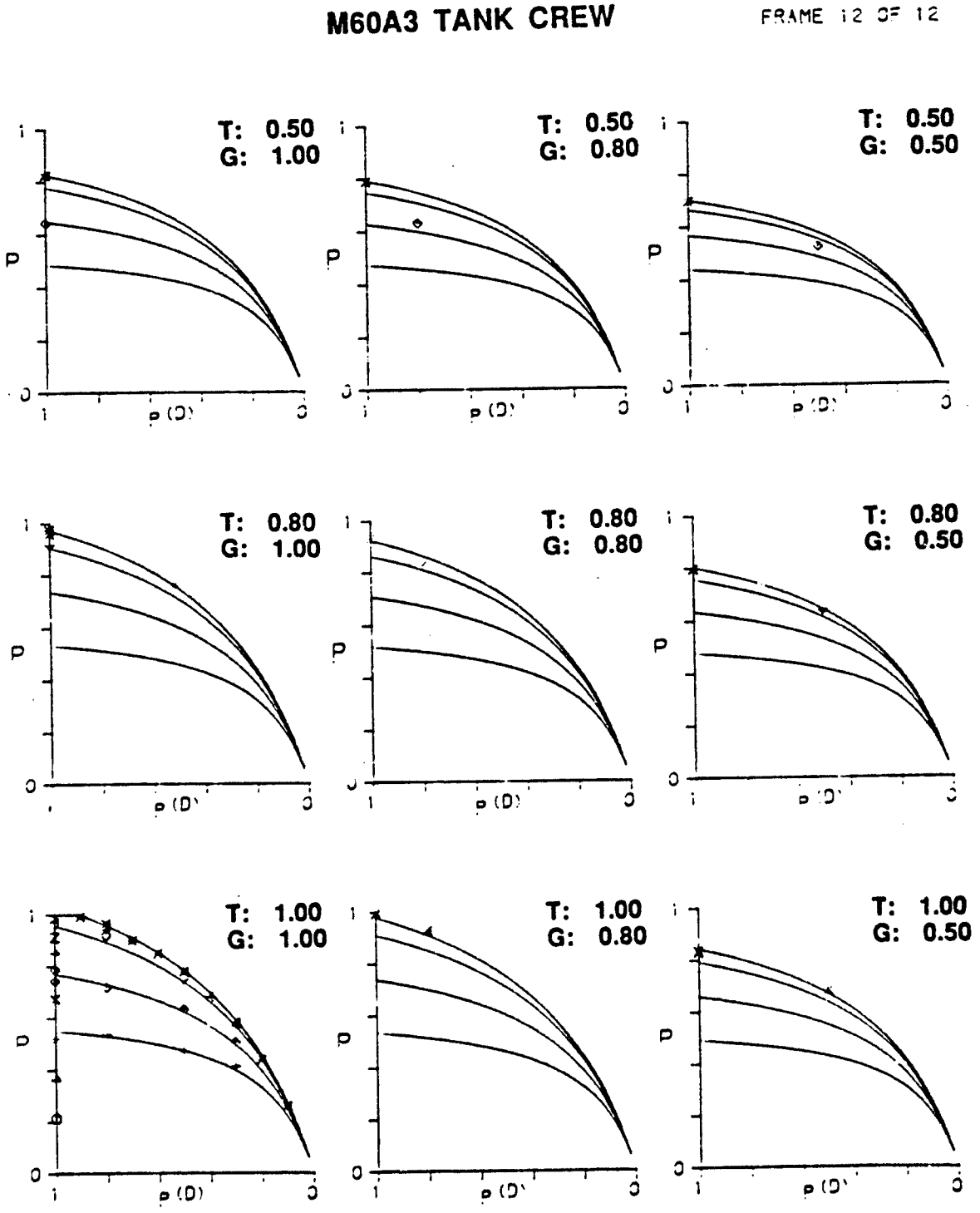



Figure 12. Final performance plot for tank crew (continued).

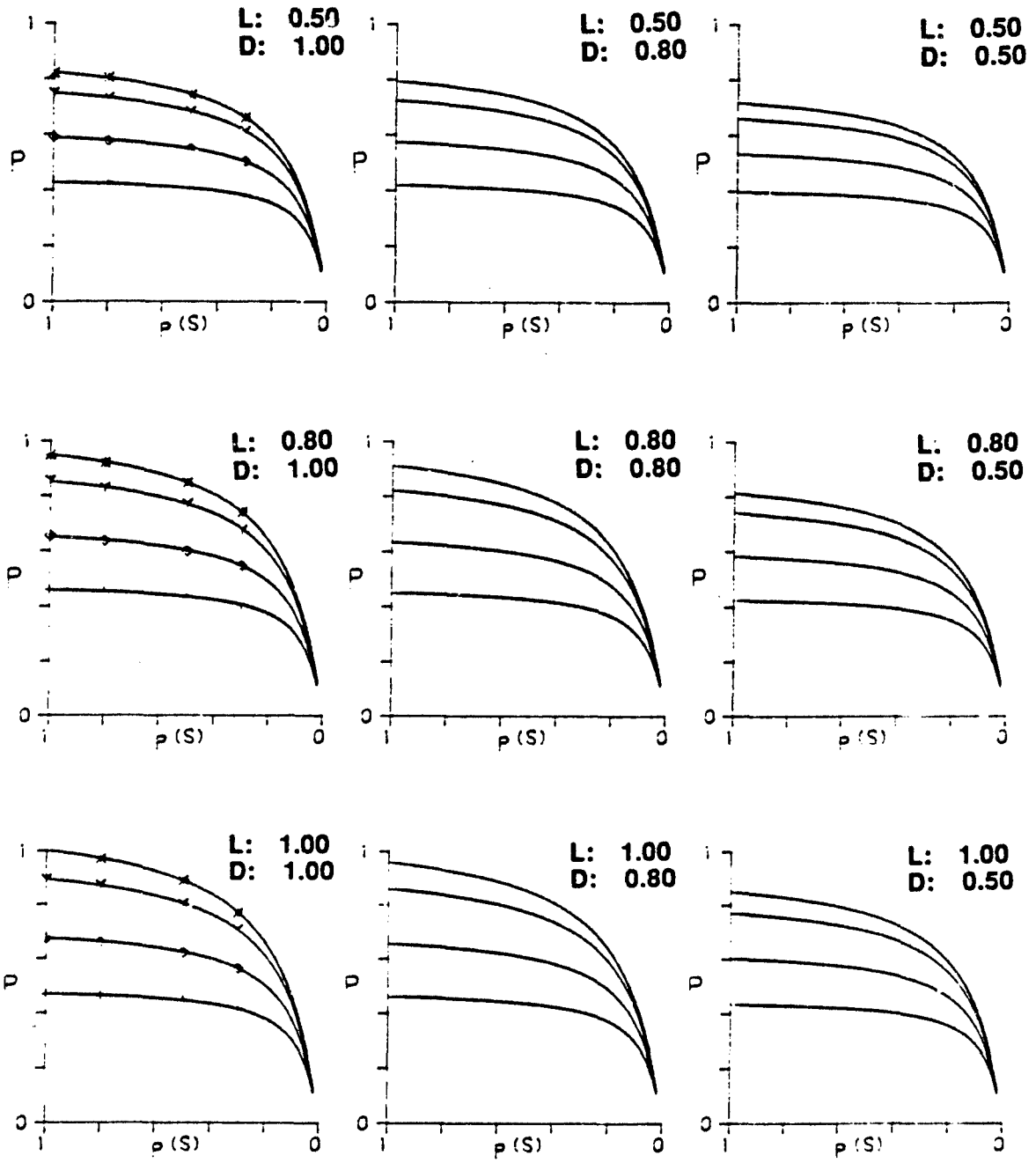



Figure 13. Final performance plot for ITV-TOW crew.

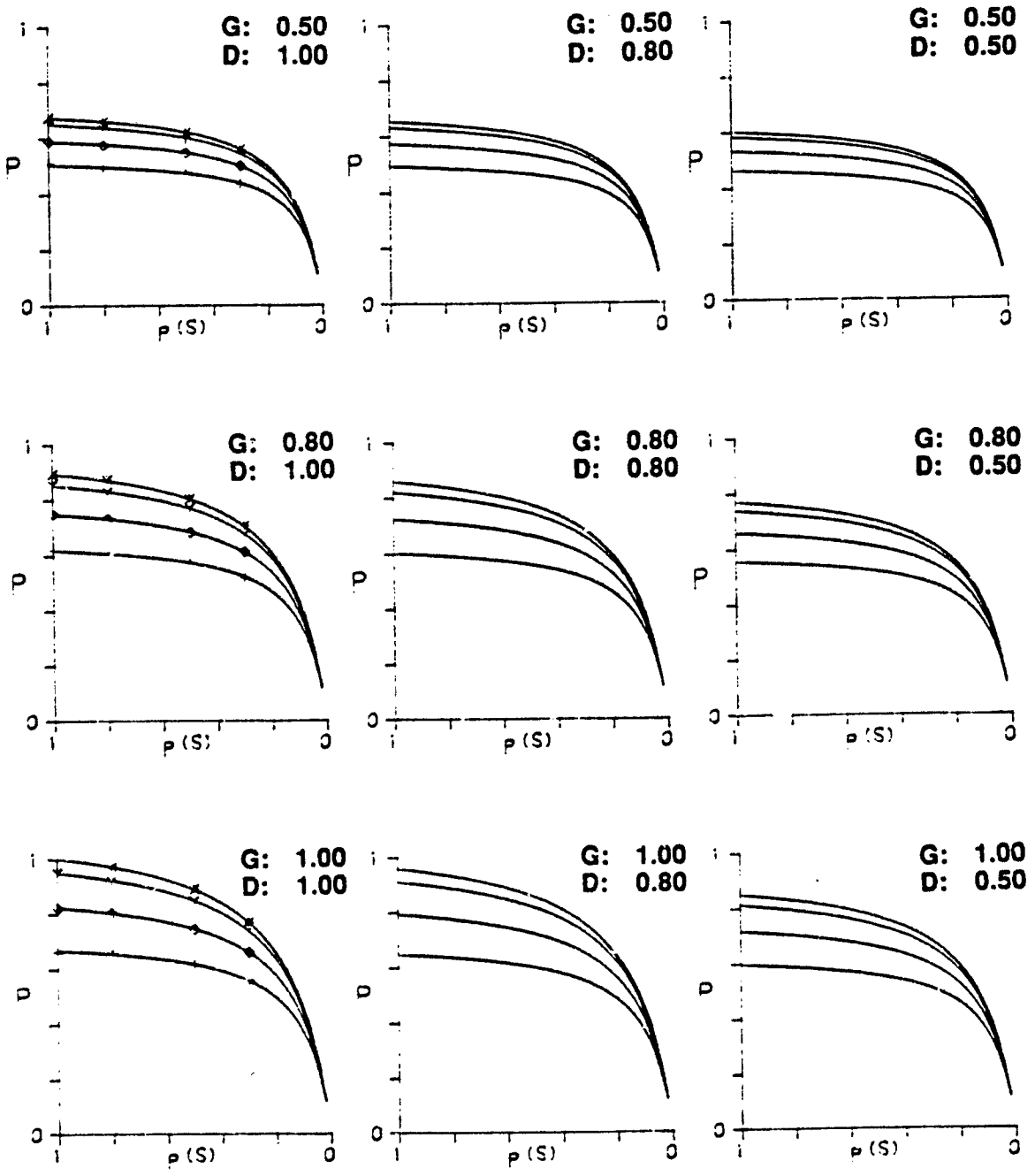



Figure 13. Final performance plot for ITV-TOW crew (continued).

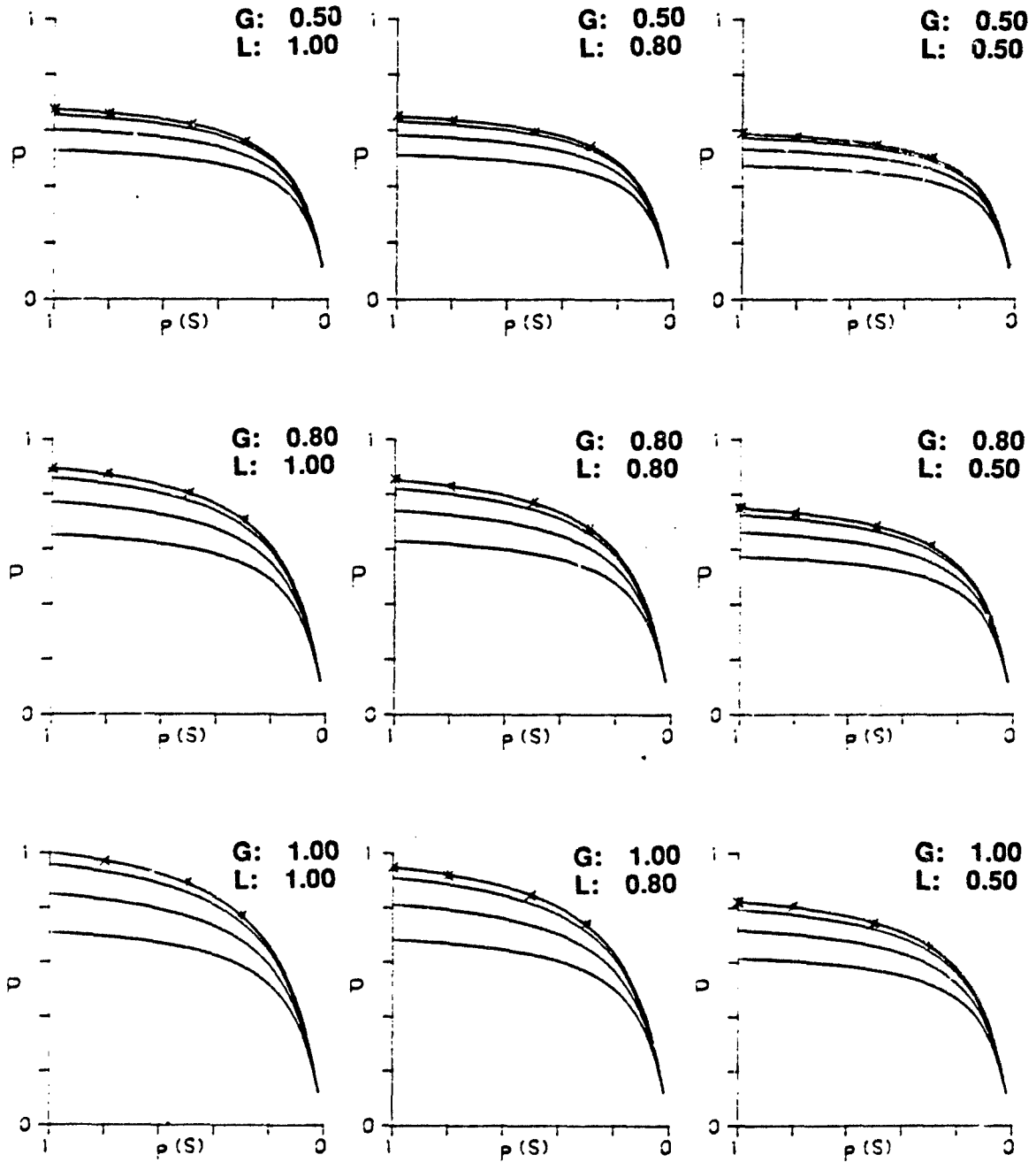



Figure 13. Final performance plot for ITV-TOW crew (continued).

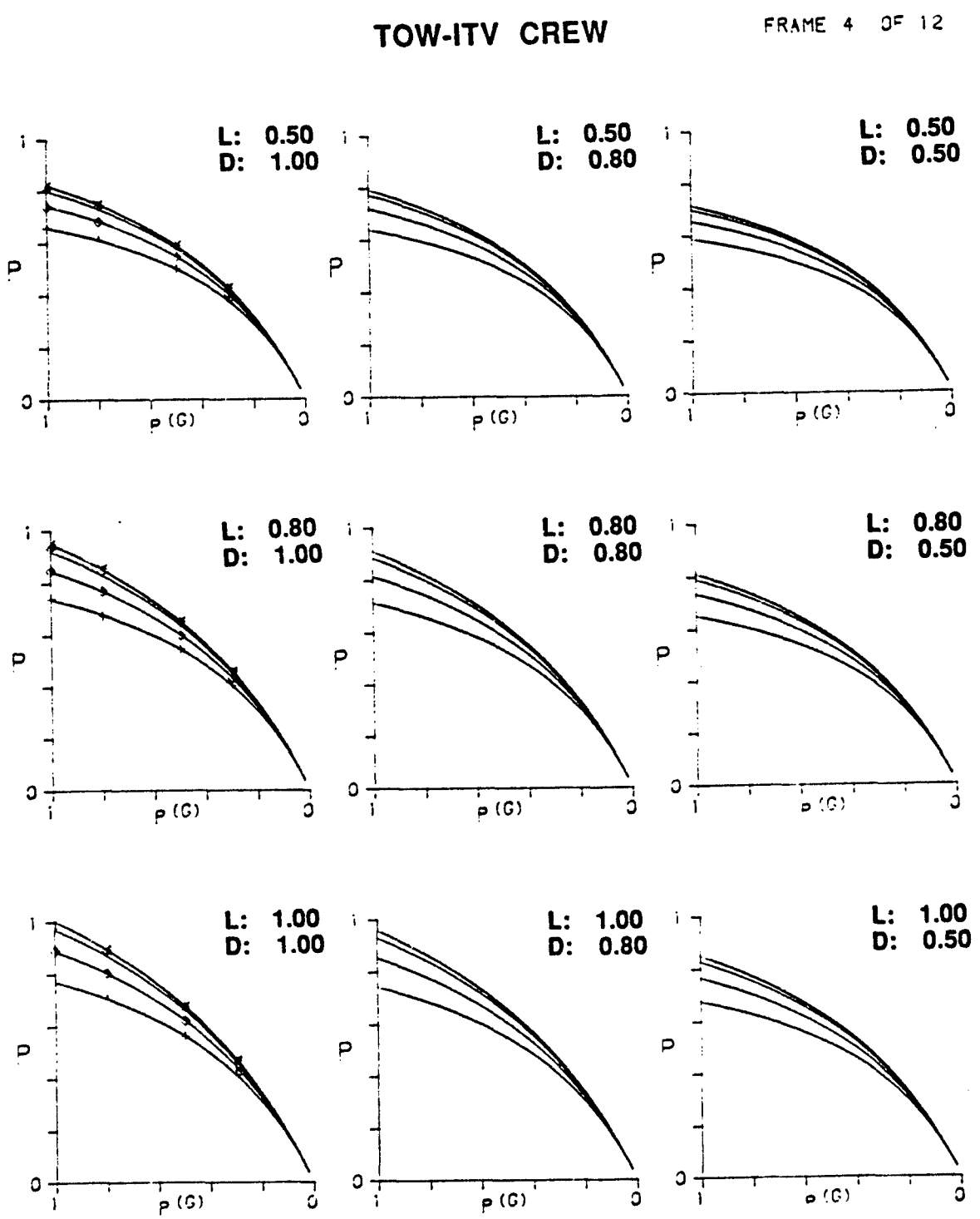



Figure 13. Final performance plot for ITV-TOW crew (continued).

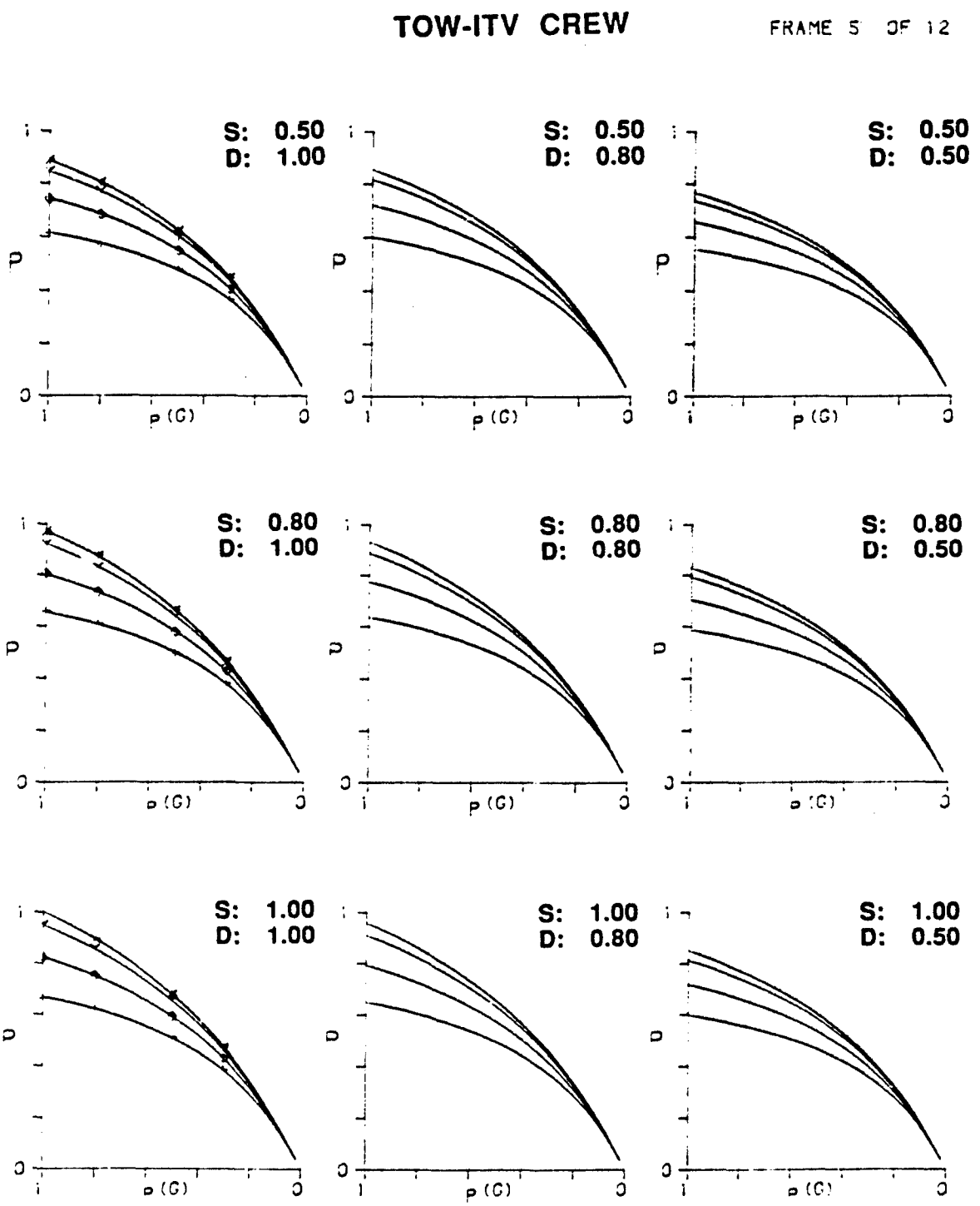



Figure 13. Final performance plot for ITV-TOW crew (continued).

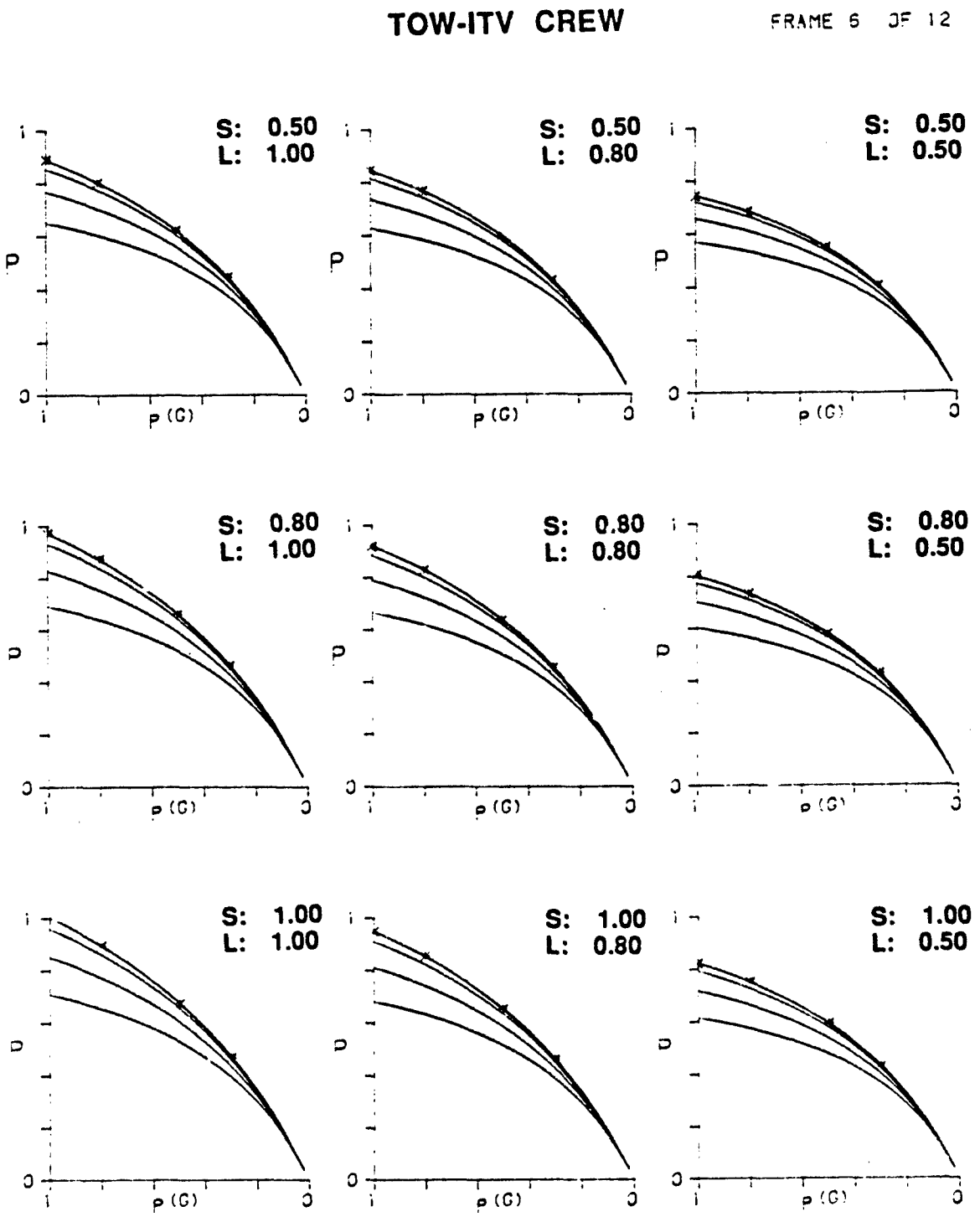



Figure 13. Final performance plot for ITV-TOW crew (continued).

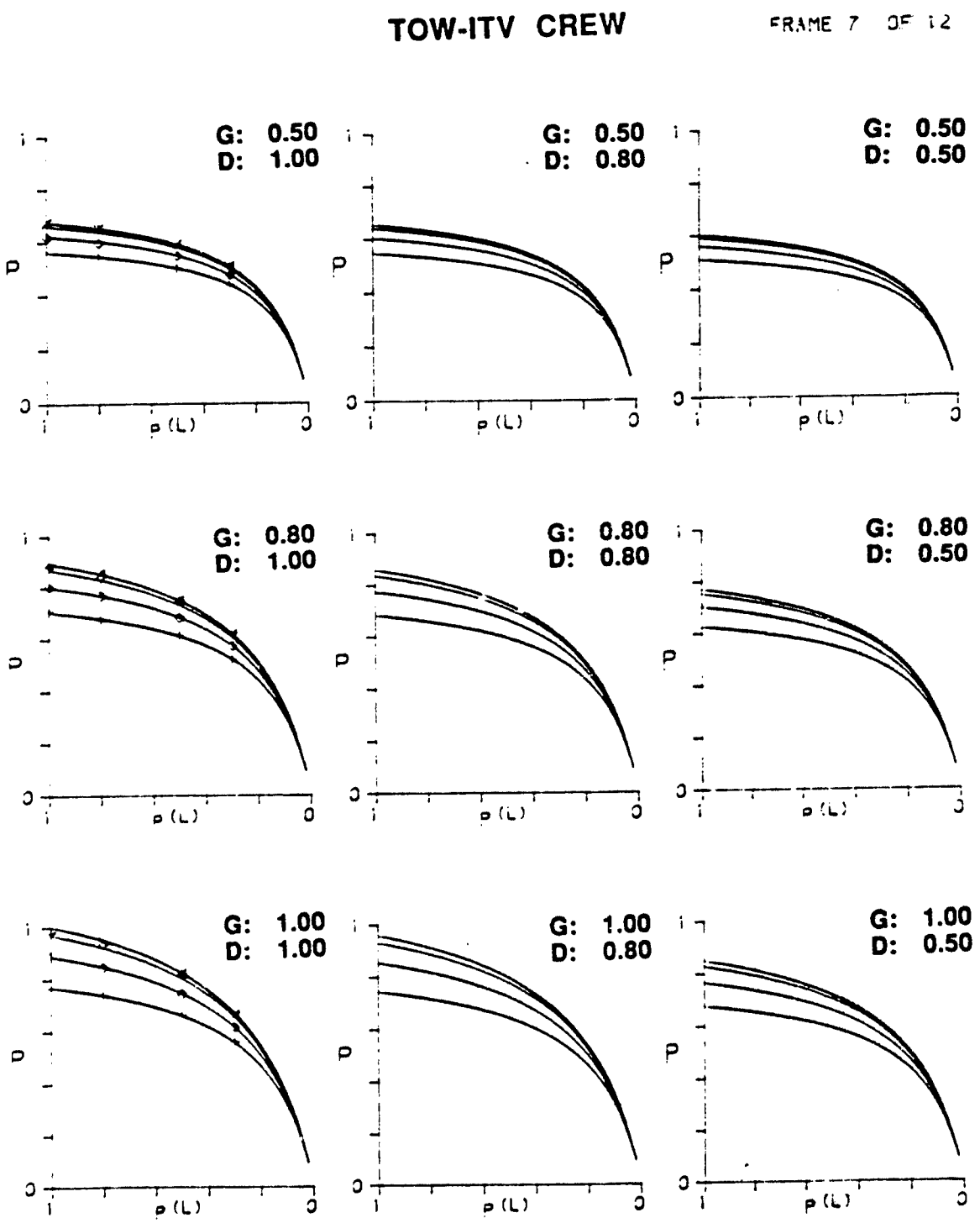



Figure 13. Final performance plot for ITV-TOW crew (continued).

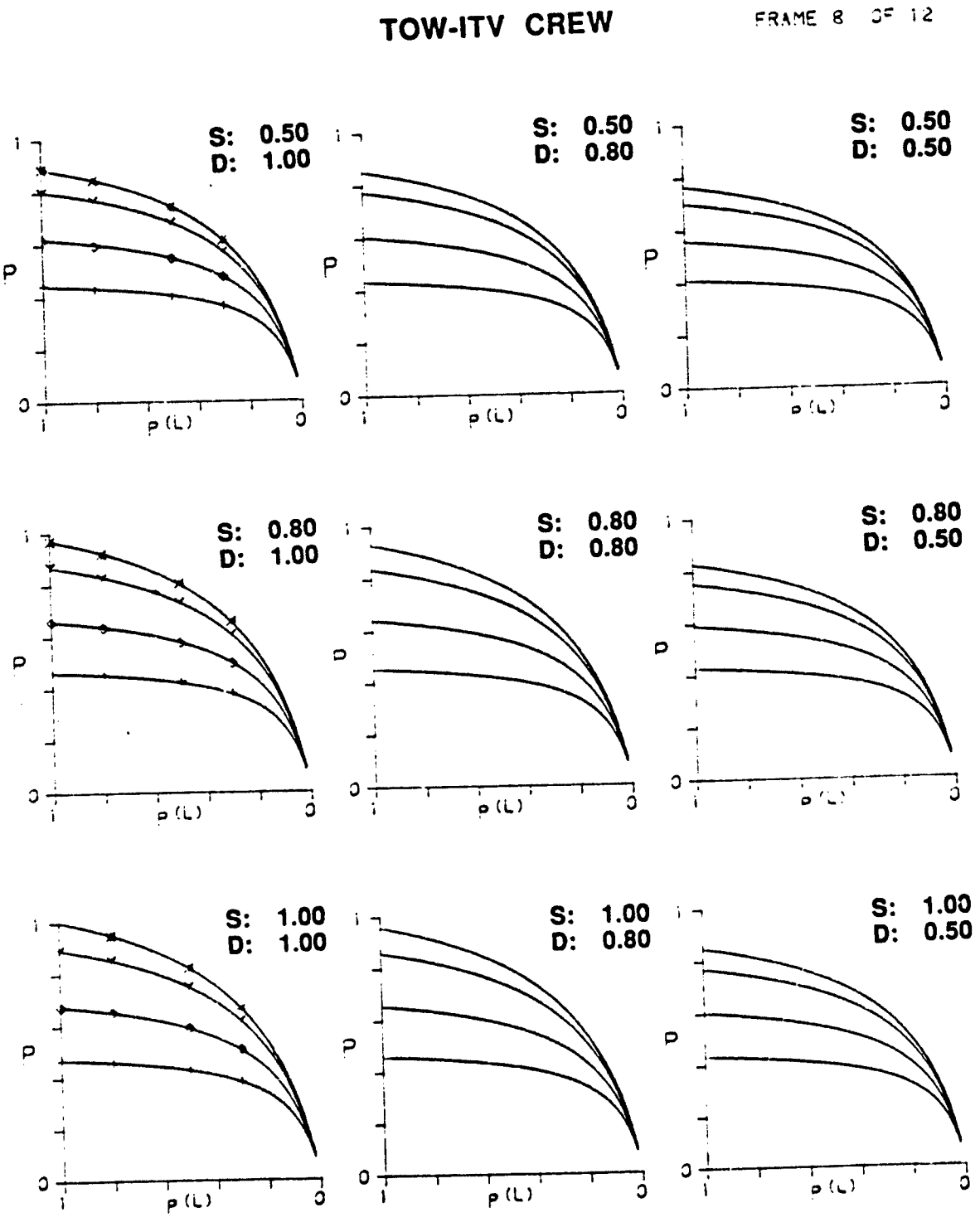



Figure 13. Final performance plot for ITV-TOW crew (continued).

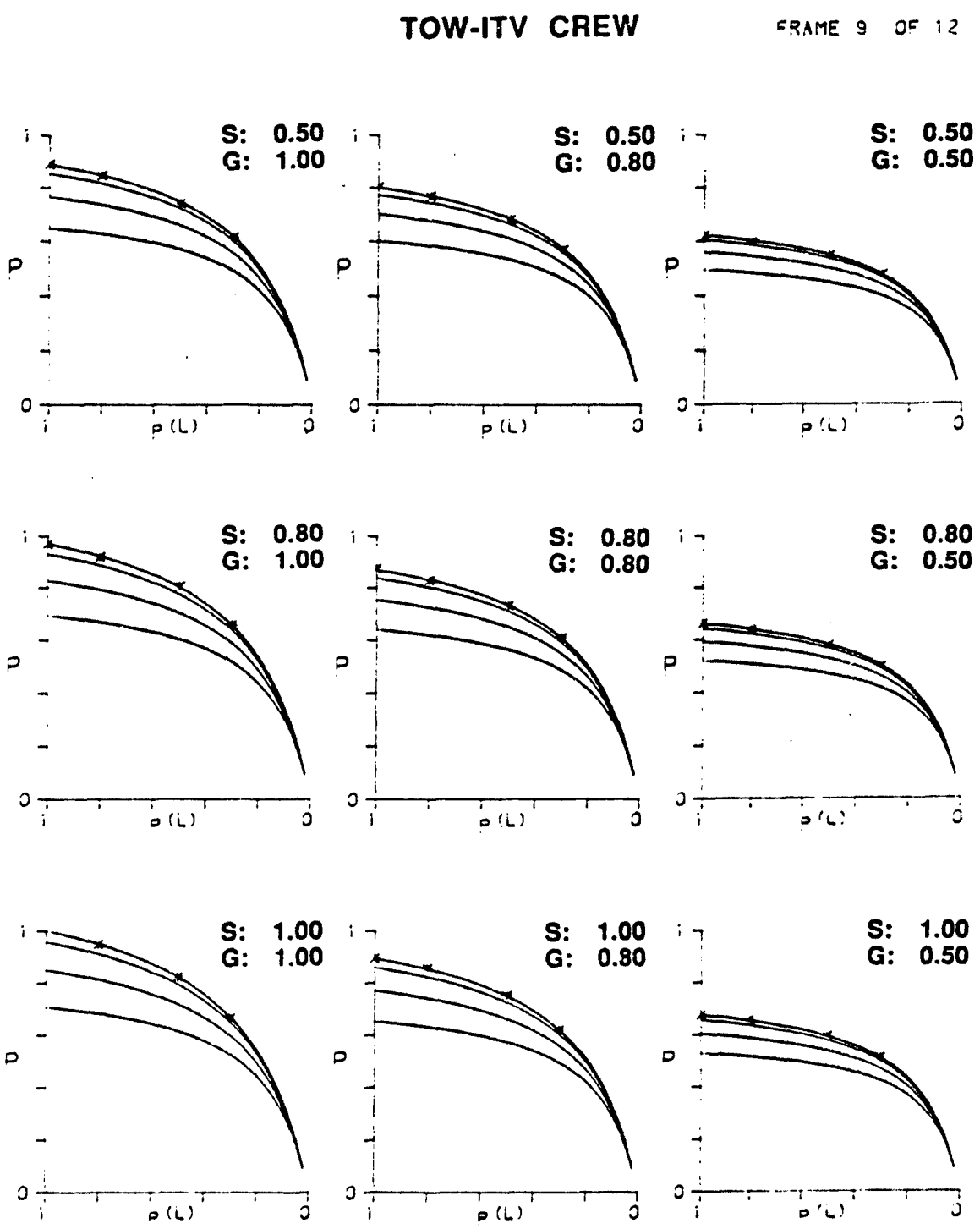



Figure 13. Final performance plot for ITV-TOW crew (continued).

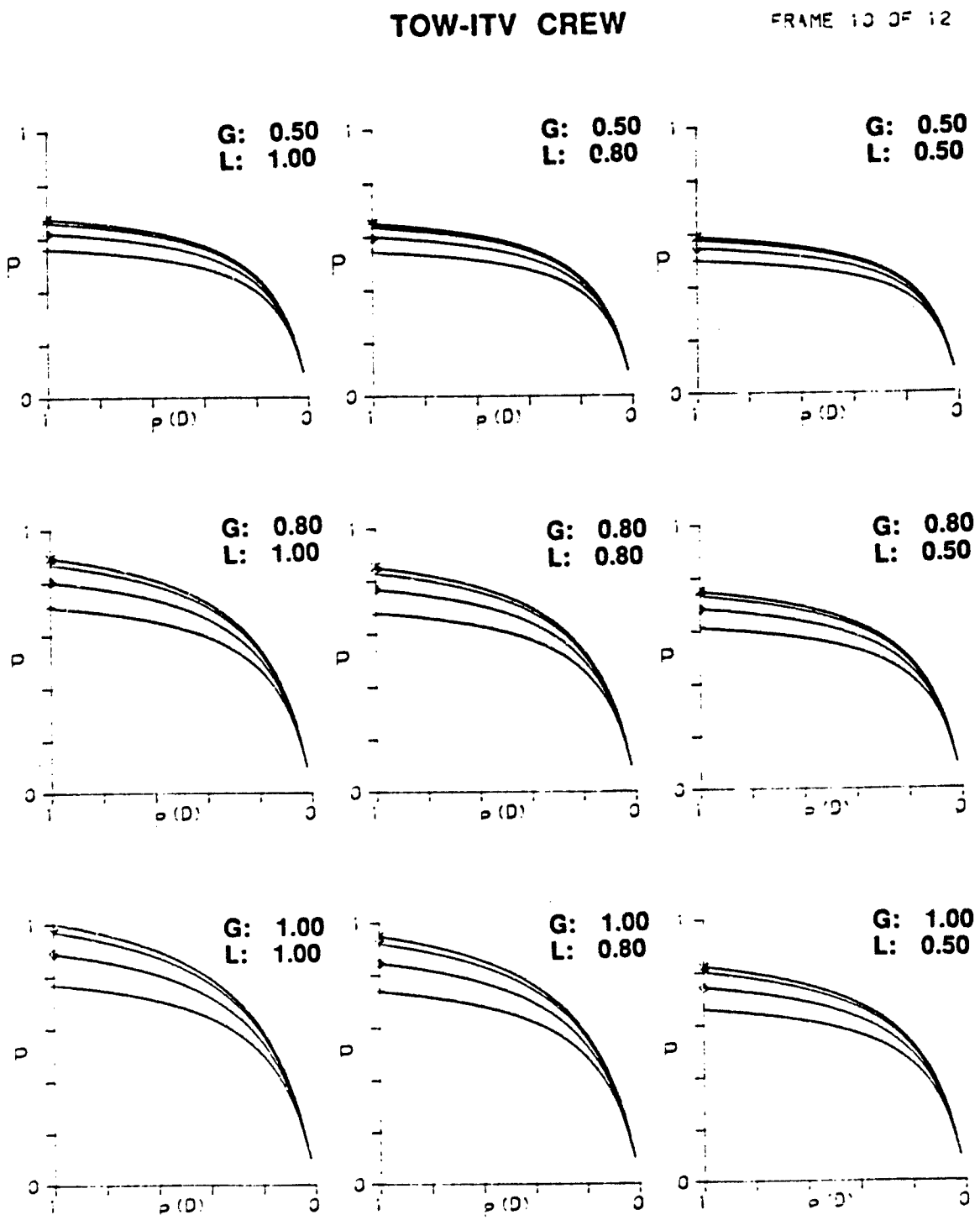



Figure 13. Final performance plot for ITV-TOW crew (continued).

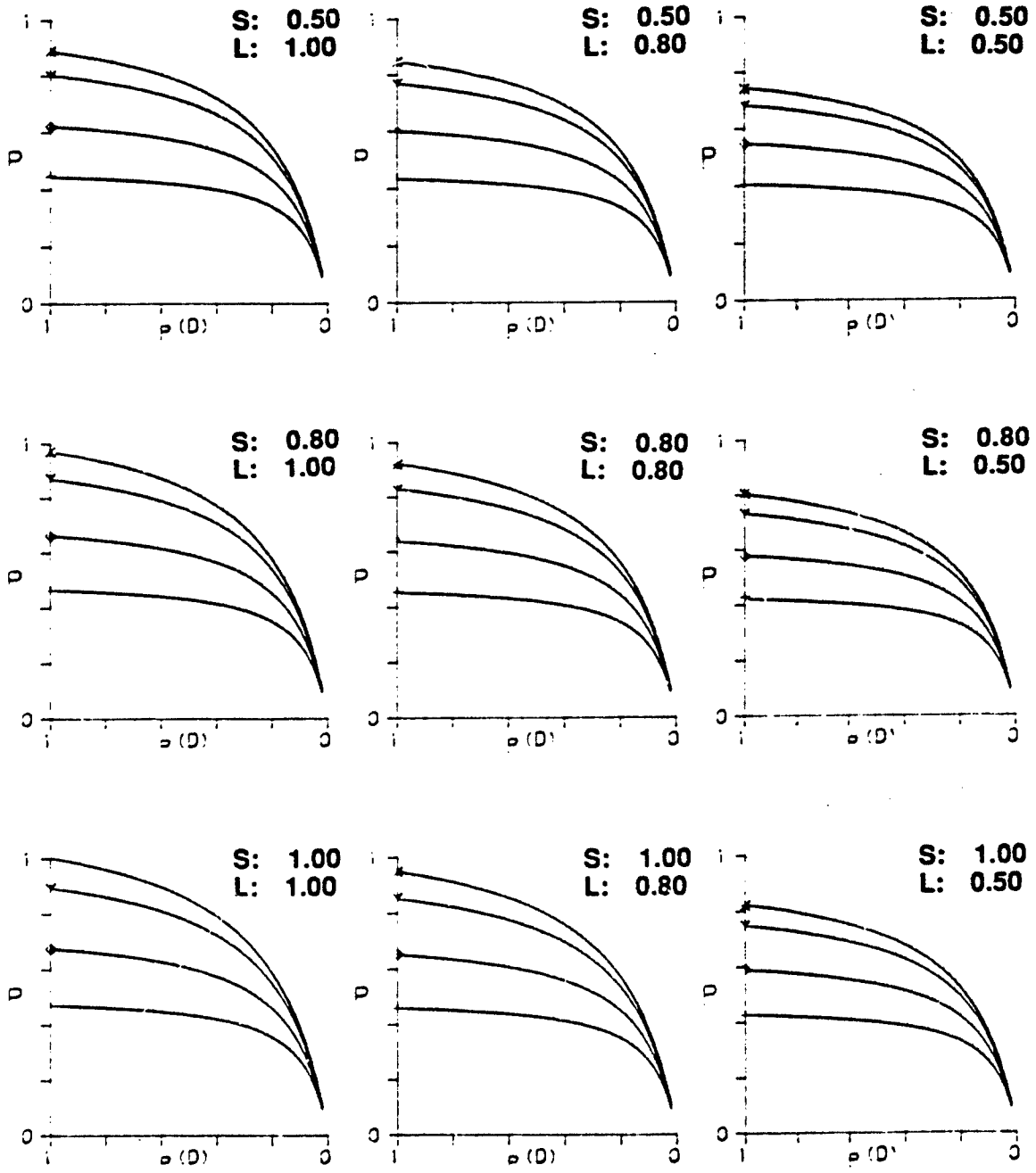



Figure 13. Final performance plot for ITV-TOW crew (continued).

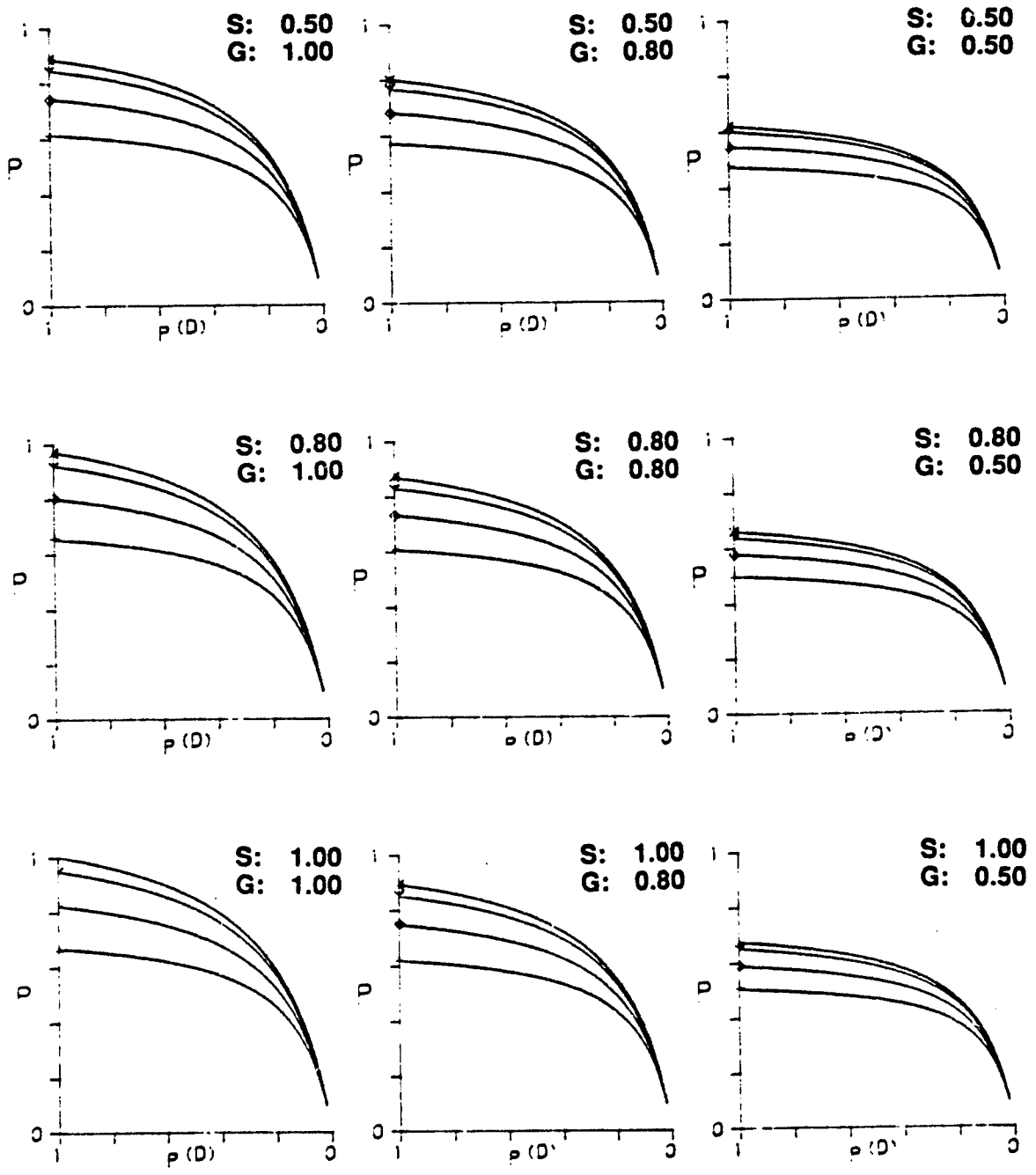



Figure 13. Final performance plot for ITV-TOW crew (continued).

## APPENDIX F

## CREW PERFORMANCE DATA

Performance as a function of dose and time is tabulated for the four crews in Tables 20 through 23. The times range from 0.2 h to 1258.93 h, and the doses range from 61.1 to 4529.9 rads.

## Table 20. Performance data grids for gun crew.

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.25 | 0.32 | 0.40 | 0.50 | 0.63 | 0.79 | 1.00 | 1.26 | 1.58 | 2.00 | 2.51 | 3.16 |
| 18 | 4529.9 | 1.0000 | 1.0000 | 0.3081 | 0.6118 | 0.4645 | 0.3462 | 0.2513 | 0.1772 | 0.1198 | 0.0765 | 0.0435 | 0.0186 | 0.0012 |
| 17 | 3516.3 | 1.0000 | 1.0000 | 1.0000 | 0.7295 | 0.6662 | 0.5583 | 0.4173 | 0.2979 | 0.2056 | 0.1706 | 0.1388 | 0.1065 | 0.0845 |
| 16 | 2729.6 | 1.0000 | 1.0000 | 1.0000 | 0.9820 | 0.7536 | 0.6249 | 0.5411 | 0.4349 | 0.3363 | 0.2832 | 0.2181 | 0.1492 | 0.1278 |
| 15 | 2118.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8425 | 0.6914 | 0.6453 | 0.5558 | 0.4556 | 0.3863 | 0.2839 | 0.1930 | 0.1727 |
| 14 | 1644.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9208 | 0.6791 | 0.6102 | 0.5146 | 0.4307 | 0.3353 | 0.2590 | 0.2449 |
| 13 | 1276.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.7464 | 0.6664 | 0.5745 | 0.4800 | 0.3909 | 0.3355 | 0.3154 |
| 12 | 991.0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8112 | 0.6748 | 0.5983 | 0.5095 | 0.4208 | 0.3663 |
| 11 | 769.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8098 | 0.6658 | 0.6188 | 0.5616 | 0.4817 |
| 10 | 597.2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8000 | 0.7261 | 0.6689 | 0.5901 |
| 9 | 463.5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8337 | 0.7200 | 0.6753 |
| 8 | 359.9 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9910 | 0.8203 | 0.7545 |
| 7 | 279.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9790 | 0.8566 |
| 6 | 216.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9655 |
| 5 | 168.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 20. Performance data grids for gun crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.98 | 5.01 | 6.31 | 7.94 | 10.00 | 12.59 | 15.85 | 19.95 | 25.12 | 31.62 | 39.81 | 50.12 | 63.10 |
| 18 | 4529.9 | 0.0008 | 0.0004 | 0.0005 | 0.0004 | 0.0004 | 0.0003 | 0.0003 | 0.0004 | 0.0004 | 0.0003 | 0.0004 | 0.0003 | 0.0001 |
| 17 | 3516.3 | 0.0538 | 0.0407 | 0.0368 | 0.0306 | 0.0262 | 0.0224 | 0.0232 | 0.0252 | 0.0278 | 0.0253 | 0.0313 | 0.0273 | 0.0177 |
| 16 | 2729.6 | 0.1069 | 0.0824 | 0.0635 | 0.0429 | 0.0351 | 0.0313 | 0.0313 | 0.0345 | 0.0411 | 0.0481 | 0.0604 | 0.0603 | 0.0474 |
| 15 | 2118.8 | 0.1521 | 0.1265 | 0.0914 | 0.0557 | 0.0463 | 0.0406 | 0.0396 | 0.0441 | 0.0550 | 0.0723 | 0.0914 | 0.1002 | 0.1024 |
| 14 | 1644.7 | 0.2270 | 0.1922 | 0.1290 | 0.0912 | 0.0681 | 0.0656 | 0.0671 | 0.0757 | 0.0892 | 0.1307 | 0.1541 | 0.1686 | 0.2239 |
| 13 | 1276.7 | 0.3003 | 0.2575 | 0.1827 | 0.1298 | 0.1076 | 0.1017 | 0.1075 | 0.1193 | 0.1334 | 0.1881 | 0.2144 | 0.2500 | 0.3457 |
| 12 | 991.0 | 0.3387 | 0.3081 | 0.2665 | 0.2215 | 0.1693 | 0.1490 | 0.1602 | 0.1722 | 0.1846 | 0.2036 | 0.2183 | 0.3389 | 0.4299 |
| 11 | 769.3 | 0.4207 | 0.3833 | 0.3510 | 0.3154 | 0.2742 | 0.2517 | 0.2664 | 0.2814 | 0.2961 | 0.3113 | 0.3513 | 0.4502 | 0.5173 |
| 10 | 597.2 | 0.5129 | 0.4637 | 0.4311 | 0.4042 | 0.3721 | 0.3467 | 0.3548 | 0.3687 | 0.3858 | 0.4035 | 0.4652 | 0.5541 | 0.5932 |
| 9 | 463.5 | 0.6061 | 0.5492 | 0.5092 | 0.4818 | 0.4512 | 0.4230 | 0.4098 | 0.4157 | 0.4343 | 0.4552 | 0.5250 | 0.6265 | 0.6470 |
| 8 | 359.2 | 0.6820 | 0.6265 | 0.5800 | 0.5503 | 0.5240 | 0.4983 | 0.4767 | 0.4789 | 0.4964 | 0.5168 | 0.5839 | 0.6792 | 0.6927 |
| 7 | 279.3 | 0.7591 | 0.7112 | 0.6615 | 0.6301 | 0.6097 | 0.6004 | 0.5996 | 0.6097 | 0.6220 | 0.6366 | 0.6736 | 0.7367 | 0.7469 |
| 6 | 216.3 | 0.8342 | 0.7991 | 0.7515 | 0.7182 | 0.7039 | 0.7174 | 0.7367 | 0.7544 | 0.7652 | 0.7754 | 0.7864 | 0.7998 | 0.8068 |
| 5 | 168.3 | 0.9626 | 0.9090 | 0.8666 | 0.8190 | 0.7975 | 0.8277 | 0.8525 | 0.8712 | 0.8973 | 0.9087 | 0.9186 | 0.9272 | 0.9347 |
| 4 | 130.6 | 1.0000 | 0.9764 | 0.9408 | 0.8989 | 0.8751 | 0.9075 | 0.9326 | 0.9518 | 0.9755 | 0.9864 | 0.9953 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 0.9854 | 0.9594 | 0.9440 | 0.9639 | 0.9861 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 0.9964 | 0.9950 | 0.9969 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 20. Performance data grids for gun crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 79.43 | 100.00 | 125.89 | 158.49 | 199.53 | 251.19 | 316.23 | 398.11 | 501.19 | 630.96 | 794.33 | 1000.00 | 1258.93 |
| 18 | 4529.9 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 17 | 3516.3 | 0.0131 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 16 | 2729.6 | 0.0521 | 0.0138 | 0.0014 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15 | 2118.8 | 0.0958 | 0.0649 | 0.0274 | 0.0153 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 14 | 1644.7 | 0.2429 | 0.1603 | 0.0869 | 0.0506 | 0.0142 | 0.0010 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 13 | 1276.7 | 0.3938 | 0.2905 | 0.1972 | 0.1110 | 0.0703 | 0.0360 | 0.0110 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 12 | 991.0 | 0.5245 | 0.4441 | 0.3742 | 0.3157 | 0.2028 | 0.1431 | 0.0782 | 0.0404 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 11 | 769.3 | 0.5838 | 0.5670 | 0.5424 | 0.5152 | 0.4331 | 0.3610 | 0.2910 | 0.2534 | 0.2245 | 0.0279 | 0.0000 | 0.0000 | 0.0000 |
| 10 | 597.2 | 0.6145 | 0.6276 | 0.6330 | 0.6247 | 0.5973 | 0.5440 | 0.4844 | 0.4318 | 0.3452 | 0.2096 | 0.1383 | 0.0000 | 0.0000 |
| 9 | 463.5 | 0.6539 | 0.6582 | 0.6598 | 0.6560 | 0.6442 | 0.6204 | 0.5809 | 0.5134 | 0.4595 | 0.3888 | 0.3068 | 0.1910 | 0.1013 |
| 8 | 359.3 | 0.6908 | 0.6878 | 0.6866 | 0.6854 | 0.6821 | 0.6788 | 0.6530 | 0.5881 | 0.5640 | 0.5310 | 0.4653 | 0.4019 | 0.3311 |
| 7 | 279.3 | 0.7401 | 0.7352 | 0.7339 | 0.7344 | 0.7362 | 0.7434 | 0.7295 | 0.6798 | 0.6749 | 0.6648 | 0.6254 | 0.5982 | 0.5610 |
| 6 | 216.8 | 0.8090 | 0.8125 | 0.8147 | 0.8142 | 0.8110 | 0.8111 | 0.8068 | 0.7964 | 0.7919 | 0.7685 | 0.7763 | 0.7729 | 0.7652 |
| 5 | 168.3 | 0.9414 | 0.9474 | 0.9527 | 0.9572 | 0.9612 | 0.9654 | 0.9698 | 0.9743 | 0.9791 | 0.9840 | 0.9893 | 0.9952 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

## Table 21. Performance data grids for FDC crew.

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.25 | 0.32 | 0.40 | 0.50 | 0.63 | 0.79 | 1.00 | 1.26 | 1.58 | 2.00 | 2.51 | 3.16 |
| 18 | 4529.9 | 1.0000 | 1.0000 | 0.8177 | 0.6337 | 0.4901 | 0.3737 | 0.2792 | 0.2023 | 0.1396 | 0.0907 | 0.0521 | 0.0222 | 0.0021 |
| 17 | 3516.3 | 1.0000 | 1.0000 | 1.0000 | 0.7969 | 0.7402 | 0.6983 | 0.6568 | 0.5955 | 0.5201 | 0.4875 | 0.4378 | 0.3552 | 0.2786 |
| 16 | 2729.6 | 1.0000 | 1.0000 | 1.0000 | 0.9836 | 0.8107 | 0.7343 | 0.7121 | 0.6577 | 0.5976 | 0.5880 | 0.5360 | 0.4368 | 0.3997 |
| 15 | 2118.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8826 | 0.7706 | 0.7409 | 0.6967 | 0.6462 | 0.6282 | 0.5734 | 0.4961 | 0.4800 |
| 14 | 1644.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9371 | 0.7659 | 0.7261 | 0.6881 | 0.6523 | 0.6008 | 0.5497 | 0.5491 |
| 13 | 1276.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8144 | 0.7571 | 0.7251 | 0.6787 | 0.6307 | 0.5980 | 0.5956 |
| 12 | 991.0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8600 | 0.7607 | 0.7362 | 0.6937 | 0.6476 | 0.6214 |
| 11 | 769.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8476 | 0.7657 | 0.7362 | 0.6976 | 0.6619 |
| 10 | 597.2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8507 | 0.7844 | 0.7434 | 0.7091 |
| 9 | 463.5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8535 | 0.7871 | 0.7642 |
| 8 | 359.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9891 | 0.8635 | 0.8162 |
| 7 | 279.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9799 | 0.8905 |
| 6 | 216.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9706 |
| 5 | 168.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 21. Performance data grids for FDC crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.98 | 5.01 | 6.31 | 7.94 | 10.00 | 12.59 | 15.85 | 19.95 | 25.12 | 31.62 | 39.81 | 50.12 | 63.10 |
| 18 | 4529.4 | 0.0012 | 0.0005 | 0.0010 | 0.0003 | 0.0007 | 0.0006 | 0.0006 | 0.0007 | 0.0007 | 0.0005 | 0.0007 | 0.0004 | 0.0001 |
| 17 | 3516.3 | 0.2154 | 0.1437 | 0.1788 | 0.1497 | 0.1297 | 0.1120 | 0.1149 | 0.1231 | 0.1320 | 0.1195 | 0.1385 | 0.1082 | 0.0526 |
| 16 | 2729.6 | 0.3596 | 0.2986 | 0.2669 | 0.1958 | 0.1673 | 0.1519 | 0.1563 | 0.1711 | 0.1910 | 0.2076 | 0.2409 | 0.2227 | 0.1686 |
| 15 | 2118.8 | 0.4613 | 0.4194 | 0.3431 | 0.2467 | 0.2046 | 0.1916 | 0.1980 | 0.2194 | 0.2491 | 0.2921 | 0.3385 | 0.3363 | 0.3110 |
| 14 | 1644.7 | 0.5478 | 0.5109 | 0.4126 | 0.3158 | 0.2785 | 0.2719 | 0.2831 | 0.3144 | 0.3498 | 0.4070 | 0.4521 | 0.4631 | 0.4841 |
| 13 | 1276.7 | 0.6020 | 0.5723 | 0.4823 | 0.4039 | 0.3626 | 0.3528 | 0.3694 | 0.4014 | 0.4417 | 0.5097 | 0.5542 | 0.5814 | 0.6446 |
| 12 | 991.0 | 0.6147 | 0.6045 | 0.5662 | 0.5169 | 0.4502 | 0.4278 | 0.4518 | 0.4774 | 0.5033 | 0.5311 | 0.5589 | 0.6420 | 0.7146 |
| 11 | 769.3 | 0.6349 | 0.6278 | 0.6130 | 0.5900 | 0.5465 | 0.5272 | 0.5496 | 0.5722 | 0.5932 | 0.6137 | 0.6434 | 0.7031 | 0.7501 |
| 10 | 597.2 | 0.6739 | 0.6610 | 0.6546 | 0.6453 | 0.6329 | 0.6143 | 0.6240 | 0.6418 | 0.6611 | 0.6807 | 0.7182 | 0.7602 | 0.7787 |
| 9 | 463.5 | 0.7330 | 0.7111 | 0.7059 | 0.6993 | 0.6900 | 0.6718 | 0.6646 | 0.6736 | 0.6934 | 0.7152 | 0.7616 | 0.8068 | 0.8113 |
| 8 | 359.8 | 0.7819 | 0.7558 | 0.7437 | 0.7350 | 0.7282 | 0.7199 | 0.7080 | 0.7131 | 0.7312 | 0.7513 | 0.7999 | 0.8342 | 0.8344 |
| 7 | 279.3 | 0.8287 | 0.8050 | 0.7835 | 0.7715 | 0.7707 | 0.7749 | 0.7758 | 0.7865 | 0.7992 | 0.8119 | 0.8424 | 0.8596 | 0.8601 |
| 6 | 216.8 | 0.8762 | 0.8562 | 0.8297 | 0.8162 | 0.8199 | 0.8329 | 0.8491 | 0.8644 | 0.8738 | 0.8806 | 0.8862 | 0.8892 | 0.8898 |
| 5 | 168.3 | 0.9634 | 0.9316 | 0.9049 | 0.8755 | 0.8696 | 0.8901 | 0.9098 | 0.9255 | 0.9418 | 0.9482 | 0.9528 | 0.9564 | 0.9594 |
| 4 | 130.6 | 1.0000 | 0.9791 | 0.9548 | 0.9260 | 0.9126 | 0.9348 | 0.9529 | 0.9676 | 0.9830 | 0.9889 | 0.9937 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 0.9855 | 0.9670 | 0.9561 | 0.9702 | 0.9861 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 0.9937 | 0.9926 | 0.9941 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 21. Performance data grids for FDC crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 79.43 | 100.00 | 125.89 | 158.49 | 199.53 | 251.19 | 316.23 | 398.11 | 501.19 | 630.96 | 794.33 | 1000.00 | 1258.93 |
| 18 | 4529.3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 17 | 3516.3 | 0.0272 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 16 | 2729.6 | 0.1388 | 0.0288 | 0.0010 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15 | 2118.8 | 0.2628 | 0.1489 | 0.0525 | 0.0357 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 14 | 1644.7 | 0.4778 | 0.3483 | 0.2013 | 0.1483 | 0.0447 | 0.0014 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 13 | 1276.7 | 0.6768 | 0.5352 | 0.4001 | 0.3169 | 0.2244 | 0.1233 | 0.0234 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 12 | 991.0 | 0.7708 | 0.6899 | 0.6065 | 0.5658 | 0.4845 | 0.4193 | 0.3273 | 0.2123 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 11 | 769.3 | 0.7812 | 0.7711 | 0.7452 | 0.7306 | 0.6903 | 0.6565 | 0.6135 | 0.5806 | 0.5325 | 0.0734 | 0.0000 | 0.0000 | 0.0000 |
| 10 | 597.2 | 0.7917 | 0.8034 | 0.8022 | 0.7998 | 0.7926 | 0.7828 | 0.7690 | 0.7458 | 0.6766 | 0.5169 | 0.4301 | 0.0001 | 0.0001 |
| 9 | 463.5 | 0.8142 | 0.8172 | 0.8177 | 0.8168 | 0.8141 | 0.8111 | 0.8015 | 0.7813 | 0.7595 | 0.7122 | 0.6269 | 0.3317 | 0.1003 |
| 8 | 359.8 | 0.8341 | 0.8323 | 0.8316 | 0.8324 | 0.8318 | 0.8320 | 0.8274 | 0.8112 | 0.8040 | 0.7892 | 0.7240 | 0.5902 | 0.3412 |
| 7 | 279.3 | 0.8534 | 0.8549 | 0.8541 | 0.8550 | 0.8558 | 0.8589 | 0.8568 | 0.8456 | 0.8459 | 0.8383 | 0.8011 | 0.7173 | 0.5741 |
| 6 | 216.8 | 0.8834 | 0.8881 | 0.8879 | 0.8880 | 0.8883 | 0.8897 | 0.8895 | 0.8871 | 0.8884 | 0.8864 | 0.8719 | 0.8301 | 0.7739 |
| 5 | 168.3 | 0.9622 | 0.9649 | 0.9676 | 0.9704 | 0.9731 | 0.9759 | 0.9787 | 0.9816 | 0.9845 | 0.9873 | 0.9897 | 0.9923 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 22. Performance data grids for tank crew.

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.25 | 0.32 | 0.40 | 0.50 | 0.63 | 0.79 | 1.00 | 1.26 | 1.58 | 2.00 | 2.51 | 3.16 |
| 18 | 4529.9 | 1.0000 | 1.0000 | 0.8224 | 0.6220 | 0.4695 | 0.3489 | 0.2527 | 0.1779 | 0.1219 | 0.0793 | 0 0463 | 0.0205 | 0.0023 |
| 17 | 3516.3 | 1.0000 | 1.0000 | 1.0000 | 0.8637 | 0.7959 | 0.7020 | 0.5676 | 0.4339 | 0.3761 | 0.3515 | 0.2983 | 0.2292 | 0.1730 |
| 16 | 2729.6 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 0.8647 | 0.7693 | 0.7155 | 0.5963 | 0.5015 | 0.4551 | 0.3552 | 0.2908 | 0.2759 |
| 15 | 2118.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9349 | 0.8368 | 0.7908 | 0 7005 | 0.5895 | 0.5222 | 0.4093 | 0.3503 | 0.3488 |
| 14 | 1644.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9765 | 0.8267 | 0.7566 | 0.6639 | 0.5762 | 0.4631 | 0.4140 | 0.4091 |
| 13 | 1276.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8803 | 0.8134 | 0.7374 | 0.6350 | 0.5283 | 0.4818 | 0.4578 |
| 12 | 991.0 | 1 0000 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9157 | 0.8235 | 0.7592 | 0.6682 | 0.5663 | 0.5021 |
| 11 | 769 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9177 | 0.8186 | 0.7736 | 0.6981 | 0.6168 |
| 10 | 597.2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9066 | 0.8538 | 0.8000 | 0.7243 |
| 9 | 463.5 | 1.0000 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9252 | 0.8487 | 0.8051 |
| 8 | 359 3 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0 9178 | 0.8762 |
| 7 | 279 3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1 0000 | 1.0000 | 1.0000 | 0.9443 |
| 6 | 216 3 | 1 0000 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9982 |
| 5 | 168.3 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101 4 | 1.0000 | 1 0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 22. Performance data grids for tank crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) 3.98 | 5.01 | 6.31 | 7.94 | 10.00 | 12.59 | 15.85 | 19.95 | 25.12 | 31.62 | 39.81 | 50.12 | 63.10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 4523.9 | 0.0014 | 0.0007 | 0.0010 | 0.0009 | 0.0008 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0004 | 0.0004 | 0.0002 | 0.0000 |
| 17 | 3516.3 | 0.1253 | 0.0761 | 0.0886 | 0.0699 | 0.0587 | 0.0494 | 0.0488 | 0.0497 | 0.0502 | 0.0433 | 0.0449 | 0.0330 | 0.0163 |
| 16 | 2729.6 | 0.2465 | 0.1817 | 0.1557 | 0.0994 | 0.0787 | 0.0706 | 0.0754 | 0.0812 | 0.0839 | 0.0861 | 0.0965 | 0.0869 | 0.0663 |
| 15 | 2118.8 | 0.3430 | 0.2941 | 0.2128 | 0.1298 | 0.0993 | 0.0925 | 0.1032 | 0.1142 | 0.1194 | 0.1318 | 0.1528 | 0.1658 | 0.1662 |
| 14 | 1644.7 | 0.4010 | 0.3674 | 0.2662 | 0.1713 | 0.1416 | 0.1374 | 0.1464 | 0.1709 | 0.1958 | 0.2243 | 0.2577 | 0.2873 | 0.3533 |
| 13 | 1276.7 | 0.4414 | 0.4160 | 0.3207 | 0.2306 | 0.1924 | 0.1831 | 0.1969 | 0.2284 | 0.2717 | 0.3148 | 0.3589 | 0.4166 | 0.5427 |
| 12 | 991.0 | 0.4731 | 0.4426 | 0.3875 | 0.3229 | 0.2477 | 0.2226 | 0.2472 | 0.2751 | 0.3044 | 0.3358 | 0.3682 | 0.5280 | 0.6542 |
| 11 | 769.3 | 0.5513 | 0.5157 | 0.4787 | 0.4368 | 0.3869 | 0.3628 | 0.3924 | 0.4226 | 0.4516 | 0.4814 | 0.5358 | 0.6544 | 0.7372 |
| 10 | 597.2 | 0.6435 | 0.5976 | 0.5698 | 0.5442 | 0.5169 | 0.4878 | 0.5075 | 0.5353 | 0.5656 | 0.5967 | 0.6700 | 0.7645 | 0.7976 |
| 9 | 463.5 | 0.7378 | 0.6812 | 0.6491 | 0.6248 | 0.5963 | 0.5655 | 0.5579 | 0.5743 | 0.6064 | 0.6419 | 0.7236 | 0.8226 | 0.8424 |
| 8 | 359.8 | 0.8103 | 0.7539 | 0.7126 | 0.6829 | 0.6605 | 0.6408 | 0.6286 | 0.6432 | 0.6713 | 0.7020 | 0.7748 | 0.8551 | 0.8687 |
| 7 | 279.3 | 0.8721 | 0.8269 | 0.7781 | 0.7433 | 0.7303 | 0.7316 | 0.7456 | 0.7677 | 0.7880 | 0.8054 | 0.8412 | 0.8862 | 0.8943 |
| 6 | 216.9 | 0.9282 | 0.8952 | 0.8453 | 0.8095 | 0.8046 | 0.8261 | 0.8536 | 0.8777 | 0.8926 | 0.9032 | 0.9114 | 0.9192 | 0.9228 |
| 5 | 168.3 | 0.9958 | 0.9631 | 0.9274 | 0.8972 | 0.8818 | 0.9102 | 0.9323 | 0.9520 | 0.9650 | 0.9720 | 0.9776 | 0.9820 | 0.9854 |
| 4 | 130.6 | 1.0000 | 0.9983 | 0.9790 | 0.9570 | 0.9411 | 0.9637 | 0.9797 | 0.9930 | 0.9991 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 0.9999 | 0.9920 | 0.9841 | 0.9939 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 22. Performance data grids for tank crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 79.43 | 100.00 | 125.89 | 158.49 | 199.53 | 251.19 | 316.23 | 398.11 | 501.19 | 630.96 | 794.33 | 1000.00 | 1258.93 |
| 18 | 4529.9 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 17 | 3516.3 | 0.0098 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 16 | 2729.6 | 0.0541 | 0.0116 | 0.0010 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15 | 2118.8 | 0.1397 | 0.0698 | 0.0300 | 0.0221 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 14 | 1644.7 | 0.3643 | 0.2186 | 0.1251 | 0.0851 | 0.0331 | 0.0025 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 13 | 1276.7 | 0.5984 | 0.4140 | 0.2912 | 0.2141 | 0.1407 | 0.0820 | 0.0242 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 12 | 991.0 | 0.7475 | 0.6312 | 0.5221 | 0.4919 | 0.3547 | 0.3080 | 0.2209 | 0.1344 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 11 | 769.3 | 0.7876 | 0.7704 | 0.7334 | 0.7342 | 0.6480 | 0.5994 | 0.5532 | 0.5107 | 0.4781 | 0.0592 | 0.0000 | 0.0000 | 0.0000 |
| 10 | 597.2 | 0.8133 | 0.8245 | 0.8338 | 0.8368 | 0.8253 | 0.7830 | 0.7683 | 0.7589 | 0.6491 | 0.4208 | 0.3461 | 0.0000 | 0.0000 |
| 9 | 463.5 | 0.8454 | 0.8445 | 0.8420 | 0.8370 | 0.8265 | 0.8048 | 0.7929 | 0.7862 | 0.7564 | 0.6832 | 0.5883 | 0.2981 | 0.0883 |
| 8 | 359.3 | 0.8693 | 0.8627 | 0.8517 | 0.8418 | 0.8329 | 0.8268 | 0.8180 | 0.8146 | 0.8237 | 0.8105 | 0.7226 | 0.5642 | 0.3098 |
| 7 | 279.3 | 0.8963 | 0.8835 | 0.8791 | 0.8736 | 0.8702 | 0.8706 | 0.8672 | 0.8663 | 0.8844 | 0.8781 | 0.8272 | 0.7173 | 0.5470 |
| 6 | 216.2 | 0.9251 | 0.9254 | 0.9263 | 0.9276 | 0.9290 | 0.9309 | 0.9323 | 0.9340 | 0.9380 | 0.9370 | 0.9169 | 0.8530 | 0.7666 |
| 5 | 168.3 | 0.9884 | 0.9810 | 0.9933 | 0.9953 | 0.9970 | 0.9985 | 0.9994 | 0.9999 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 79.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 23. Performance data grids for ITV-TOW crew.

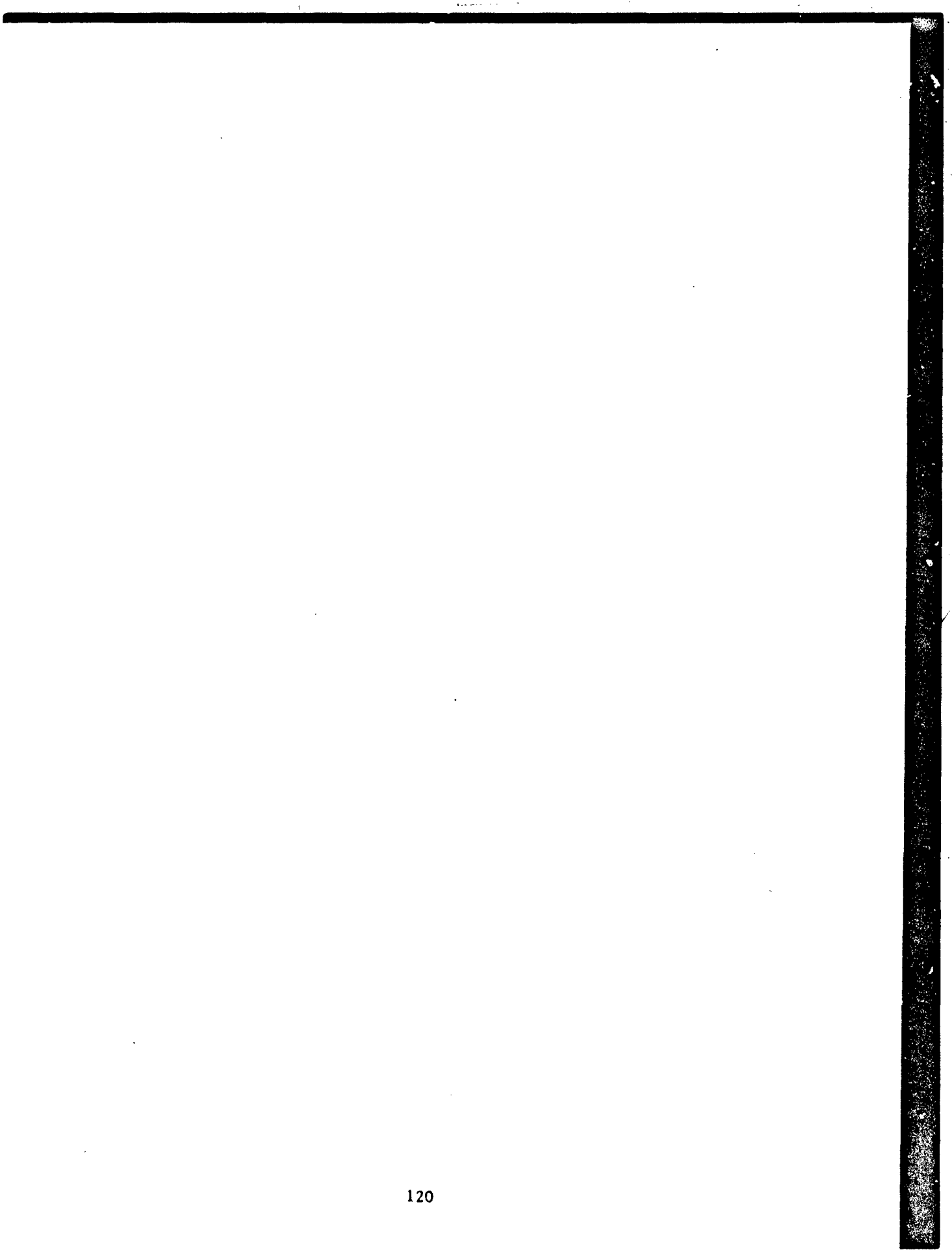
| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.25 | 0.32 | 0.40 | 0.50 | 0.63 | 0.79 | 1.00 | 1.26 | 1.58 | 2.00 | 2.51 | 3.16 |
| 18 | 4525.9 | 1.0000 | 1.0000 | 0.8152 | 0.6817 | 0.4887 | 0.3721 | 0.2755 | 0.2008 | 0.1411 | 0.0947 | 0.0578 | 0.0282 | 0.0042 |
| 17 | 3516.3 | 1.0000 | 1.0000 | 1.0000 | 0.8714 | 0.8157 | 0.7017 | 0.5129 | 0.4033 | 0.3054 | 0.2663 | 0.2340 | 0.1920 | 0.1613 |
| 16 | 2729.6 | 1.0000 | 1.0000 | 1.0000 | 0.9852 | 0.9705 | 0.7744 | 0.6853 | 0.5697 | 0.4457 | 0.3827 | 0.3228 | 0.2408 | 0.2039 |
| 15 | 2118.9 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9263 | 0.8466 | 0.8021 | 0.7004 | 0.5676 | 0.4703 | 0.3814 | 0.2893 | 0.2465 |
| 14 | 1644.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9598 | 0.9349 | 0.7619 | 0.6474 | 0.5356 | 0.4255 | 0.3467 | 0.3145 |
| 13 | 1276.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.8817 | 0.8233 | 0.7293 | 0.6062 | 0.4778 | 0.4181 | 0.3828 |
| 12 | 991.0 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9135 | 0.8326 | 0.7536 | 0.6452 | 0.5225 | 0.4419 |
| 11 | 769.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9213 | 0.8217 | 0.7766 | 0.6954 | 0.5979 |
| 10 | 597.2 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9034 | 0.8609 | 0.8136 | 0.7345 |
| 9 | 463.5 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9187 | 0.8577 | 0.8135 |
| 8 | 359.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9951 | 0.9129 | 0.8782 |
| 7 | 279.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9890 | 0.9363 |
| 6 | 216.8 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9839 |
| 5 | 168.3 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 73.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 23. Performance data grids for ITV-TOW crew (continued).

| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3.98 | 5.01 | 6.31 | 7.94 | 10.00 | 12.59 | 15.85 | 19.95 | 25.12 | 31.62 | 39.81 | 50.12 | 63.10 |
| 18 | 4529.9 | 0.0032 | 0.0018 | 0.0014 | 0.0013 | 0.0011 | 0.0009 | 0.0010 | 0.0011 | 0.0012 | 0.0013 | 0.0017 | 0.0014 | 0.0007 |
| 17 | 3516.3 | 0.1257 | 0.0770 | 0.0583 | 0.0480 | 0.0406 | 0.0344 | 0.0362 | 0.0412 | 0.0477 | 0.0549 | 0.0747 | 0.0725 | 0.0567 |
| 16 | 2729.6 | 0.1668 | 0.1231 | 0.0911 | 0.0604 | 0.0487 | 0.0432 | 0.0434 | 0.0498 | 0.0643 | 0.0875 | 0.1209 | 0.1421 | 0.1483 |
| 15 | 2118.8 | 0.2081 | 0.1693 | 0.1237 | 0.0726 | 0.0568 | 0.0520 | 0.0505 | 0.0594 | 0.0810 | 0.1202 | 0.1665 | 0.2031 | 0.2543 |
| 14 | 1644.7 | 0.2829 | 0.2417 | 0.1676 | 0.1019 | 0.0848 | 0.0822 | 0.0846 | 0.1009 | 0.1236 | 0.1787 | 0.2220 | 0.2691 | 0.3622 |
| 13 | 1276.7 | 0.3554 | 0.3122 | 0.2254 | 0.1552 | 0.1281 | 0.1212 | 0.1304 | 0.1512 | 0.1788 | 0.2343 | 0.2731 | 0.3318 | 0.4716 |
| 12 | 991.0 | 0.4014 | 0.3583 | 0.3052 | 0.2506 | 0.1987 | 0.1649 | 0.1836 | 0.2044 | 0.2270 | 0.2542 | 0.2793 | 0.4516 | 0.5819 |
| 11 | 769.3 | 0.5162 | 0.4598 | 0.4175 | 0.3742 | 0.3284 | 0.3081 | 0.3330 | 0.3583 | 0.3831 | 0.4086 | 0.4681 | 0.6043 | 0.6835 |
| 10 | 597.2 | 0.6369 | 0.5671 | 0.5231 | 0.4877 | 0.4517 | 0.4284 | 0.4487 | 0.4717 | 0.4993 | 0.5289 | 0.6141 | 0.7261 | 0.7623 |
| 9 | 463.5 | 0.7378 | 0.6644 | 0.6094 | 0.5720 | 0.5340 | 0.5036 | 0.5163 | 0.5414 | 0.5416 | 0.5753 | 0.6644 | 0.7759 | 0.7975 |
| 8 | 359.8 | 0.8087 | 0.7445 | 0.6852 | 0.6431 | 0.6104 | 0.5841 | 0.5735 | 0.5889 | 0.6145 | 0.6454 | 0.7192 | 0.8151 | 0.8230 |
| 7 | 279.3 | 0.8692 | 0.8218 | 0.7645 | 0.7200 | 0.6943 | 0.6922 | 0.7066 | 0.7286 | 0.7476 | 0.7665 | 0.8023 | 0.8563 | 0.8645 |
| 6 | 216.8 | 0.9226 | 0.8912 | 0.8411 | 0.7991 | 0.7826 | 0.8027 | 0.8280 | 0.8504 | 0.8643 | 0.8757 | 0.8864 | 0.8977 | 0.9030 |
| 5 | 168.3 | 0.9819 | 0.9504 | 0.9168 | 0.8877 | 0.8708 | 0.8928 | 0.9138 | 0.9301 | 0.9436 | 0.9512 | 0.9562 | 0.9619 | 0.9667 |
| 4 | 130.6 | 1.0000 | 0.9867 | 0.9651 | 0.9457 | 0.9329 | 0.9494 | 0.9645 | 0.9765 | 0.9875 | 0.9928 | 0.9970 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 0.9931 | 0.9817 | 0.9747 | 0.9839 | 0.9933 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 0.9986 | 0.9976 | 0.9989 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table 23. Performance data grids for ITV-TOW crew (continued).

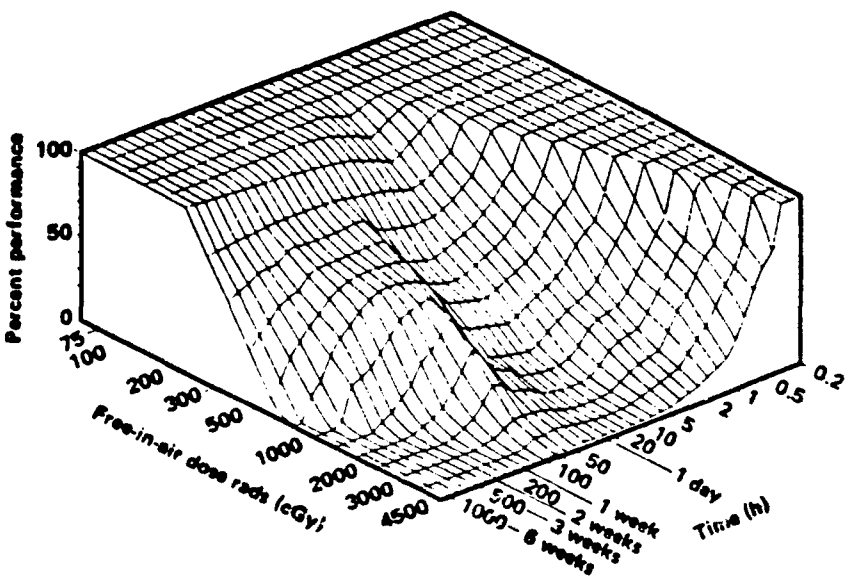
| Grid Line | Dose (rads) | Time Grid Lines (h) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 79.43 | 100.00 | 125.89 | 158.49 | 199.53 | 251.19 | 316.23 | 398.11 | 501.19 | 630.96 | 794.33 | 1000.00 | 1258.93 |
| 18 | 4529.9 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 17 | 3516.3 | 0.0508 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 16 | 2729.6 | 0.1790 | 0.0589 | 0.0161 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 15 | 2118.8 | 0.3026 | 0.2161 | 0.1158 | 0.0534 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 14 | 1644.7 | 0.4290 | 0.3359 | 0.2147 | 0.1032 | 0.0330 | 0.0037 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 13 | 1276.7 | 0.5557 | 0.4676 | 0.3413 | 0.1711 | 0.1291 | 0.0651 | 0.0231 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 12 | 991.0 | 0.6855 | 0.6295 | 0.5725 | 0.4863 | 0.2918 | 0.1901 | 0.1079 | 0.0513 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 11 | 769.3 | 0.7541 | 0.7426 | 0.7311 | 0.6993 | 0.5602 | 0.4635 | 0.3682 | 0.3108 | 0.2704 | 0.0352 | 0.0000 | 0.0000 | 0.0000 |
| 10 | 597.2 | 0.7821 | 0.7899 | 0.7928 | 0.7828 | 0.7501 | 0.6983 | 0.6010 | 0.5178 | 0.4015 | 0.2281 | 0.1782 | 0.0000 | 0.0000 |
| 9 | 463.5 | 0.8050 | 0.8077 | 0.8086 | 0.8044 | 0.7916 | 0.7712 | 0.7189 | 0.6156 | 0.5361 | 0.4397 | 0.3855 | 0.2520 | 0.1111 |
| 8 | 359.9 | 0.8272 | 0.8250 | 0.8256 | 0.8255 | 0.8286 | 0.8212 | 0.7920 | 0.7082 | 0.6621 | 0.6173 | 0.5611 | 0.4819 | 0.3416 |
| 7 | 279.3 | 0.8600 | 0.8600 | 0.8600 | 0.8612 | 0.8698 | 0.8690 | 0.8552 | 0.8087 | 0.7879 | 0.7661 | 0.7257 | 0.6649 | 0.5685 |
| 6 | 216.8 | 0.9066 | 0.9091 | 0.9105 | 0.9114 | 0.9129 | 0.9137 | 0.9118 | 0.9053 | 0.8986 | 0.8874 | 0.8647 | 0.8238 | 0.7696 |
| 5 | 168.3 | 0.9705 | 0.9737 | 0.9764 | 0.9783 | 0.9811 | 0.9834 | 0.9854 | 0.9875 | 0.9833 | 0.9910 | 0.9926 | 0.9953 | 1.0000 |
| 4 | 130.6 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 3 | 101.4 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 78.7 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 1 | 61.1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |



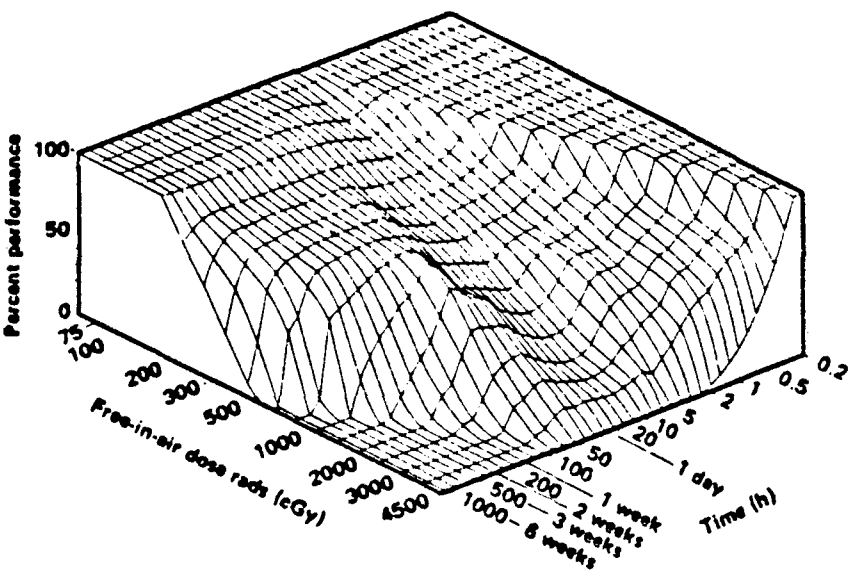
## APPENDIX G

## THREE-DIMENSIONAL PLOTS OF PERFORMANCE OVER DOSE AND TIME

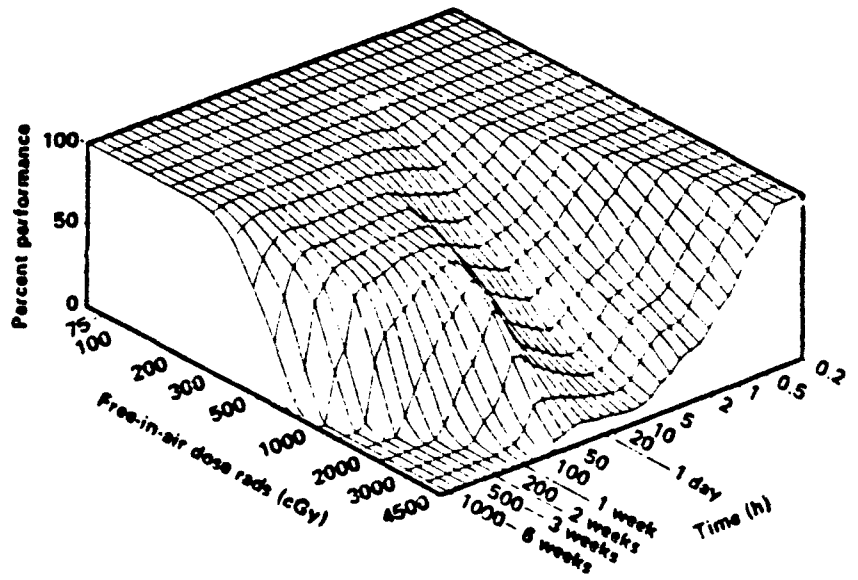
a. Gun crew.



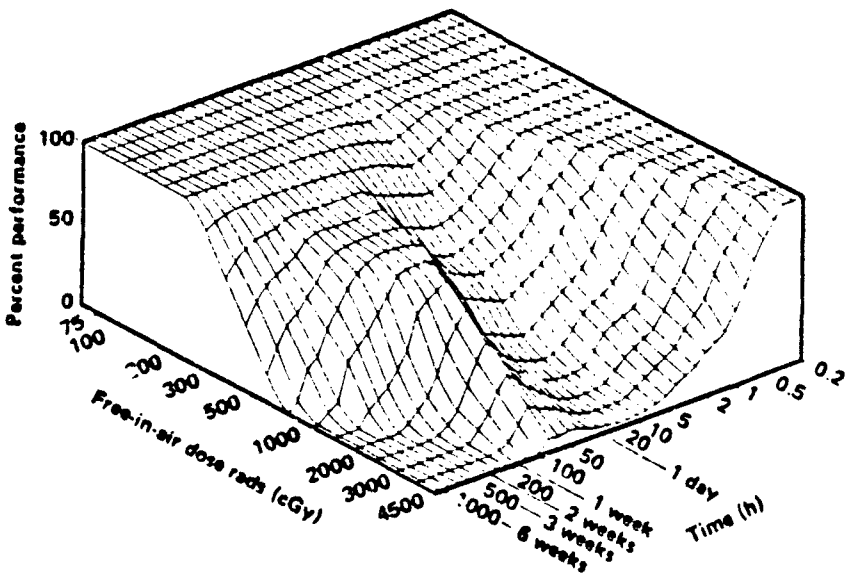

b. FDC crew.



c. Tank crew.




d. ITV-TOW crew.

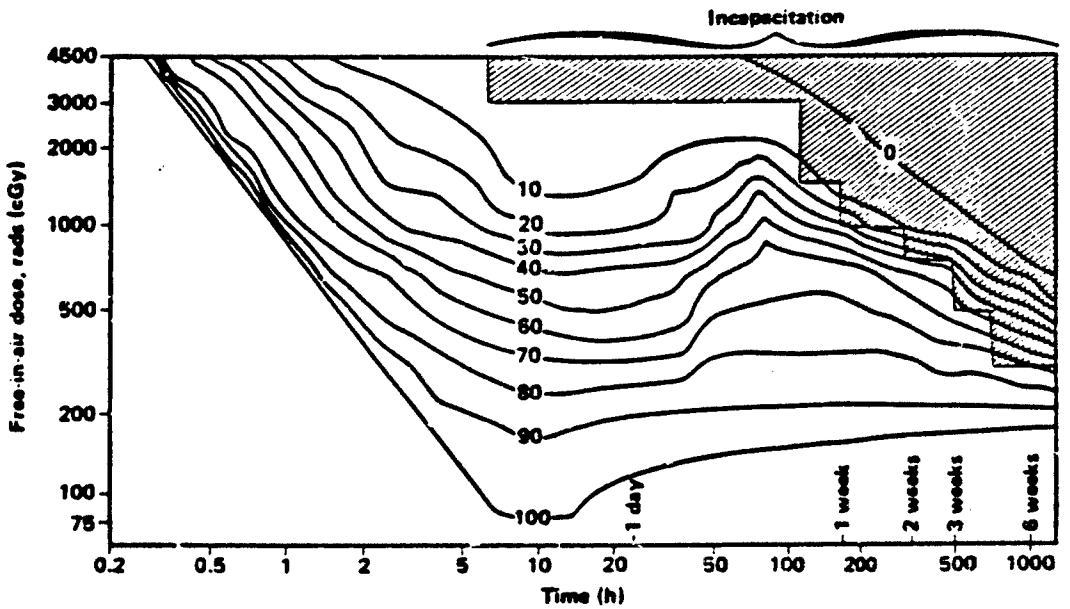


APPENDIX H

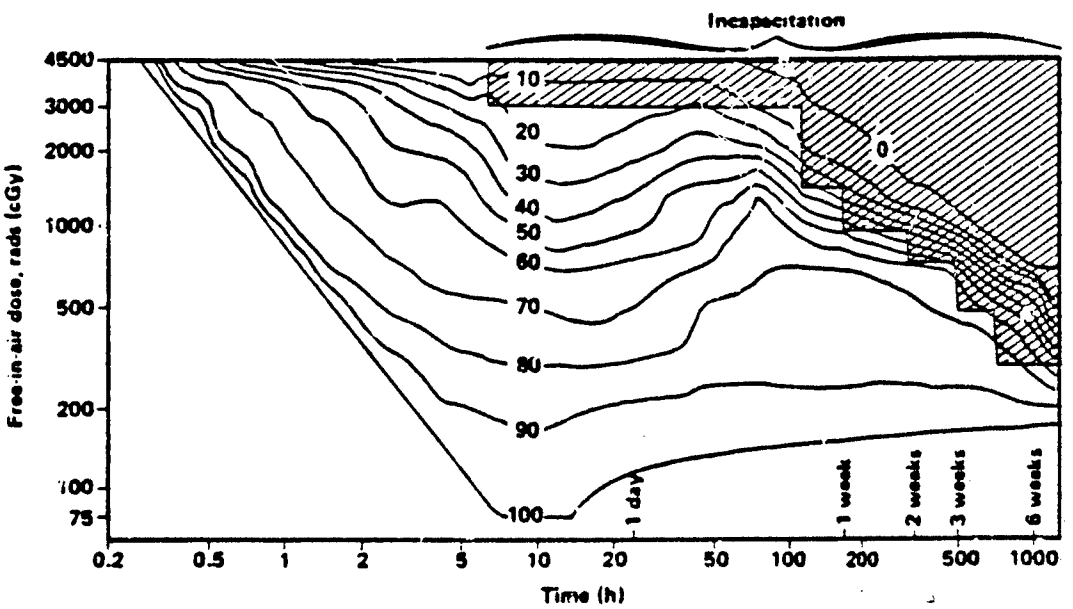
CONTOUR PLOTS OF PERFORMANCE OVER DOSE AND TIME

(10 PERCENT PERFORMANCE INTERVALS)

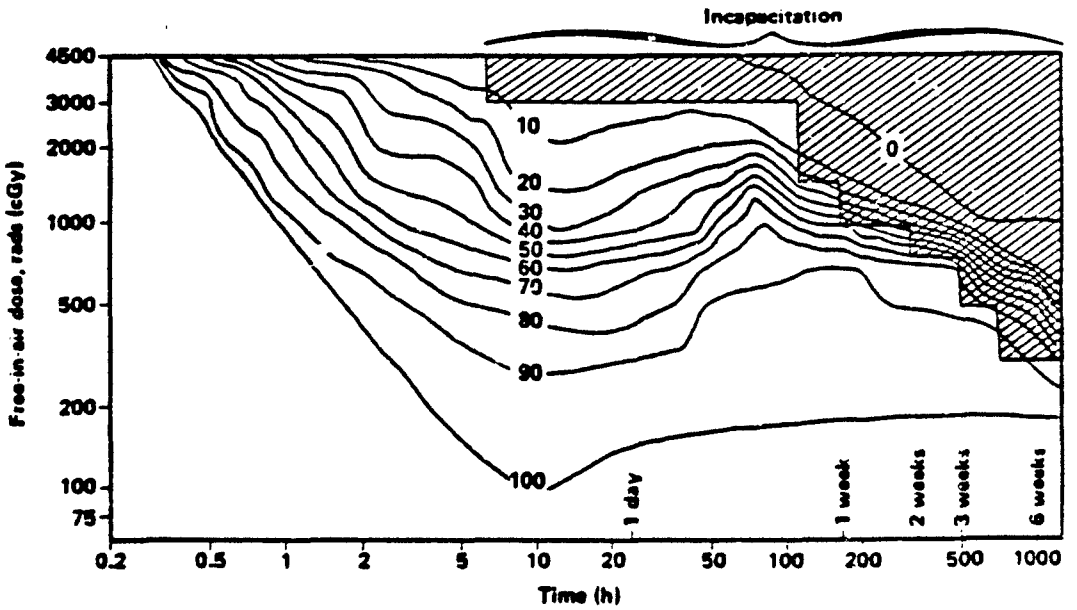
a. Gun crew.



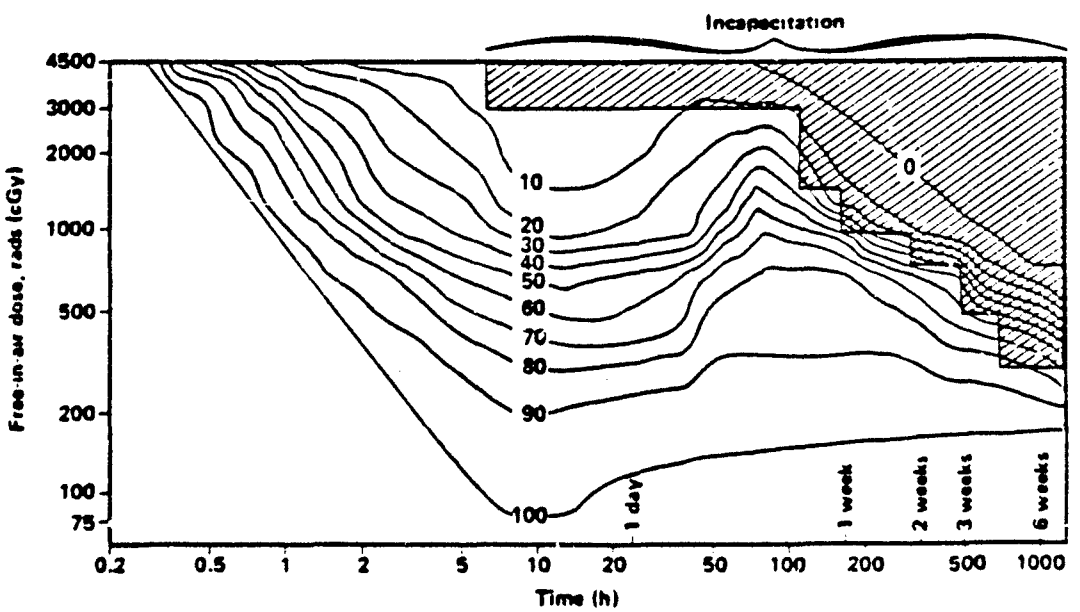

b. FDC crew.



c. Tank crew.




d. ITV-TOW crew.



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